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Total control system for shotcreting

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ABSTRACT

This system offers automated and labor-effectiveness environment in the site control of shotcreting on NATM method tunnel work; and also reduces QSCA (quick setting cement additive).

The total control of 'Spraying robot'; 'Conveyer-pump of concrete' and 'Supply-system of quick setting cement additive' enables automatic shotcreting by setting the proper quantity of cement and QSCA beforehand.

This system reduces of the rebound shotcrete and QSCA by adding the most proper volume of QSCA to the working area.

Therefore it more able to save the cost of construction than usual methods.

Moreover, Homogeneous shotcreting is available by controlling the volume of QSCA in accordance with the measured value of the height of the blowing area and output quantity concrete from conveyer-pump.

INTRODUCTION

The NATM method adopted widely in tunnel work in mountain districts seeks to reinforce the bedrock by shotcreting immediately after excavation. In shotcreting, a quick setting cement additive (QSCA) must be added for quicker setting of concrete sprayed on the ceiling and walls of the tunnel. In this process, to regulate the addition volume of QSCA according to the condition of the working surfaces as well as to the quantity of shotcrete output is important in order to prevent uneven setting. The conventional method, however, cannot easily change the rate of QSCA addition in response to the movement of the shotcrete spraying orifice. This sometimes leads to wasting of costly QSCA and further to lowering of the cost-effectiveness.

The "Total Control System for Shotcreting" developed by TOA CORPORATION can provide not only total control of the spraying position and shotcrete output quantity, but also automatic regulation of the rate of QSCA addition.

1. OUTLINE OF THE SYSTEM

The total control system for shotcreting not only realizes automatic addition of QSCA in proper quantity as well as automated and labor-saving site control of shotcreting in tunnel work, but also enables high-quality shotcreting. In the conventional method, three spraying units; namely "spraying robot," "concrete conveyer-pump" and "quick setting cement

additive supply system," are manually operated separately, making total site control very difficult.

The total control system for shotcreting, which interfaces with the above three spraying units, offers very effective shotcreting by automatically adding QSCA in the most suitable ratio to the surface to be sprayed (working area) and the output quantity of shotcrete.

2. ACHIEVEMENTS OF THE DEVELOPED TECHNIQUE

1) The spraying nozzle position areas can be automatically detected in accordance with tunnel shape.

There are three areas as shown in Fig. 1.

① Ceiling area
② Shoulder area
③ Side wall area (Lower half area)

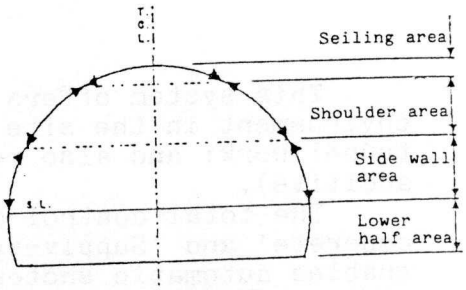


Fig. 1

2) The rate of QSCA addition for each area can be set by the field engineer.

Working area	Rate of addition
① Ceiling area	K1 %
② Shoulder area	K2 %
③ Side wall area (Lower half area)	K3 %

3) Automatic shotcreting can be performed with the rate of QSCA addition set in accordance to the output quantity of shotcrete.

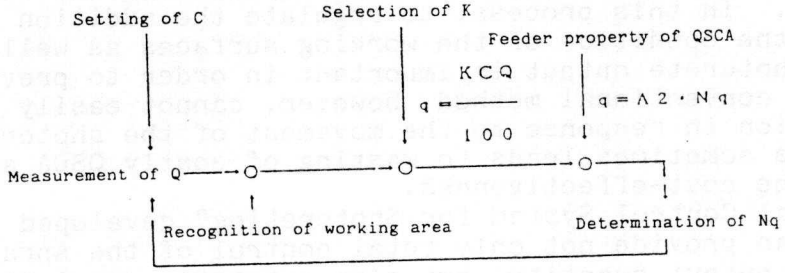


Fig. 2

C : Weight of cement contained in shotcrete (kg/m³)
Q : Output quantity of shotcrete (m³/hr)
K : Rate of QSCA addition (%)
q : Output quantity of QSCA (kg/hr)
Nq : QSCA feeder speed (rpm)
A2 : Constant (Feeder property of QSCA supply system)

4) Shotcreting display and can be obtained. Time, shotcrete output quantity, QSCA addition rate.

3. DEVELOPED TECHNIQUE RESTRICTIONS

1) QSCA addition rate can be set in two modes, namely manual (conventional) or automatic mode (developed technique). Users can select either mode.

2) In the manual mode, the upper limit of the output quantity of QSCA can be determined by the field engineer.

3) In general, the spraying robots, concrete conveyer pumps and QSCA supply systems are leased. Therefore, this automatic QSCA addition method can be applied to every machine of every model.

4. QSCA QUANTITY (RATE) TO BE ADDED

Definition: The QSCA quantity to be added is the quotient expressed in % obtained by dividing the weight of QSCA to be added to shotcrete by the weight of the cement contained in shotcrete.

$$K = \frac{q}{C \cdot Q} \times 100 \ (\%)$$

Q : Output quantity of shotcrete (m^3/hr)
C : Weight of cement contained in shotcrete (kg/m^3)
q : Output quantity of QSCA (kg/hr)
K : Rate of QSCA addition (%)

5. SHOTCRETING METHOD USING THE DEVELOPED TECHNIQUE

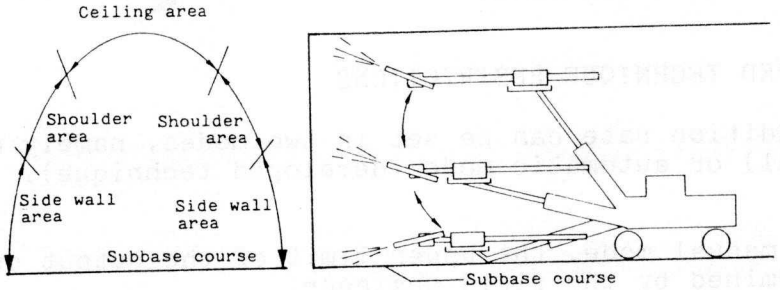
1) Setting of C (weight of cement contained in shotcrete)
C is set by a digital switch to the specified value.

2) Measurement of Q (shotcrete output quantity)
The output quantity of shotcrete from the spraying unit can be, irrespective of rotary- or stroke-type, expressed by the following equation.

$$Q = \frac{E \cdot V}{S} \times 3600 \times \frac{1}{100} \ (m^3/hr)$$

E : Volumetric efficiency (%)
V : Rotary type --- Net capacity of rotor (m^3)
Stroke type --- Net capacity of two cylinders (m^3)
S : Rotary type --- Time required for 1 rotation (sec)
Stroke type --- Time required for 1 reciprocation (sec)

3) Recognition of spraying areas
When a spraying robot performs shotcreting from the side wall to the ceiling area, the distance between the boom tip and the subbase course increases in proportion to the rise of the spraying nozzle. Thus, the working area subjected to shotcreting can be recognized by measuring the distance between the boom tip and the subbase course.



H : Distance between subbase course and boom tip at spraying (H is measured using ultrasonic waves.)
H1 : Maximum H at spraying on the side wall area
H2 : Maximum H at spraying on the shoulder area

Fig. 3

Because the relationship between H and the working areas depends on the tunnel sections and the equipments machines, recognition of working areas according to the site condition is required. H1 and H2 should be set by the field engineer using a digital switch in accordance with the site condition. H should be measured continuously.

$H \leqq H1$	Side wall area and lower half area
$H1 < H < H2$	Shoulder area
$H2 \leqq H$	Ceiling area

4) Selection of K (Rate of QSCA addition)

The rate of QSCA addition for each area should be set by field engineer using the digital switch. That is, K is selected among the values set according to the measured H.

Working area	Setting	Selection
Ceiling area	K1	$\leftarrow H \leqq H2$
Shoulder area	K2	$\leftarrow H1 < H < H2$
Side wall area and lower half area	K3	$\leftarrow H \leqq H1$

5) QSCA output quantity

The quantity of QSCA for each area is obtained by operation and varies in accordance with the measured height.

Working area	Operation	Unit
$H \leqq H2 \rightarrow$	q1 = K1CQ/100	(kg/hr)
$H1 < H < H2 \rightarrow$	q2 = K2CQ/100	(kg/hr)
$H \leqq H1 \rightarrow$	q3 = K3CQ/100	(kg/hr)

6) Setting of A2 (Feeder property of QSCA supply system)

Feeder property can be obtained by calibration in which the output quantity q is measured while the feeder rpm Nq changes.

q is expressed as a linear function of Nq shown as the following equation.

$$q = A2 \cdot Nq \ (kg/hr)$$

Therefore, the feeder property can be expressed as A2, which must be set by digital switch.

7) Determination of Nq (QSCA feeder rpm)

Feeder Nq must be determined so that q from the site condition agree with q from the feeder property.

$$\frac{KCQ}{100} = A2 \cdot Nq$$

Thus,

$$Nq = \frac{KCQ}{100A2}$$

In this system, Nq is determined by the inverter.

Based on the above, the automatic regulation mechanism of QSCA quantity addition for the "total control system for shotcreting" is illustrated in Fig. 4, and the side elevation as well as the panoramic photograph of the completed system are shown in Fig. 5.

Total control system for shotcreting

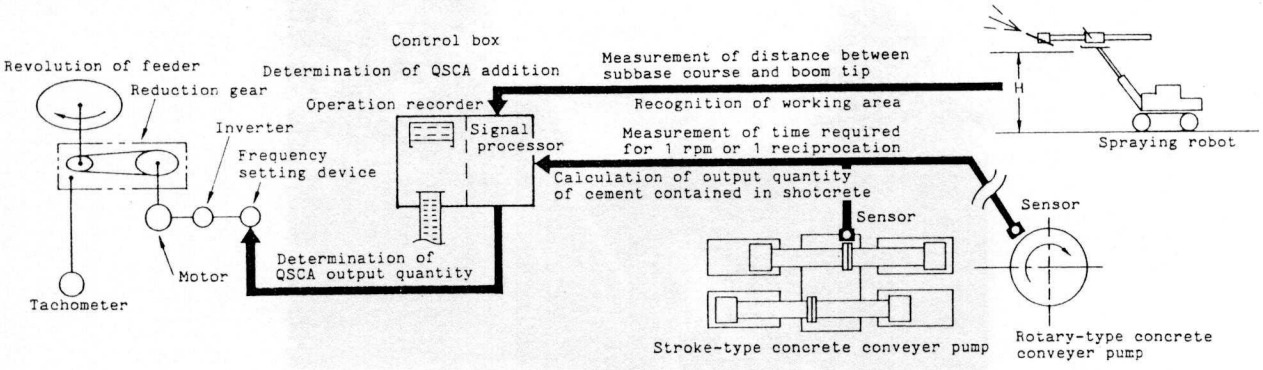
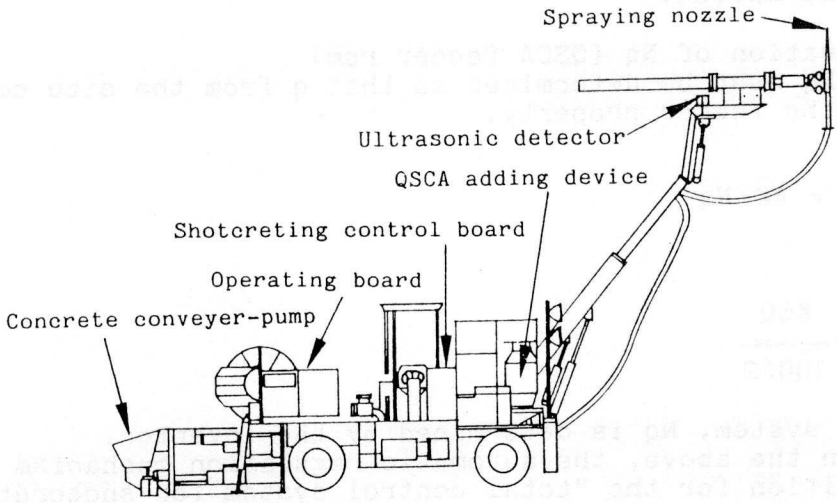


Fig. 4

Side elevation of total control system for shotcreting



Panoramic photograph of the system

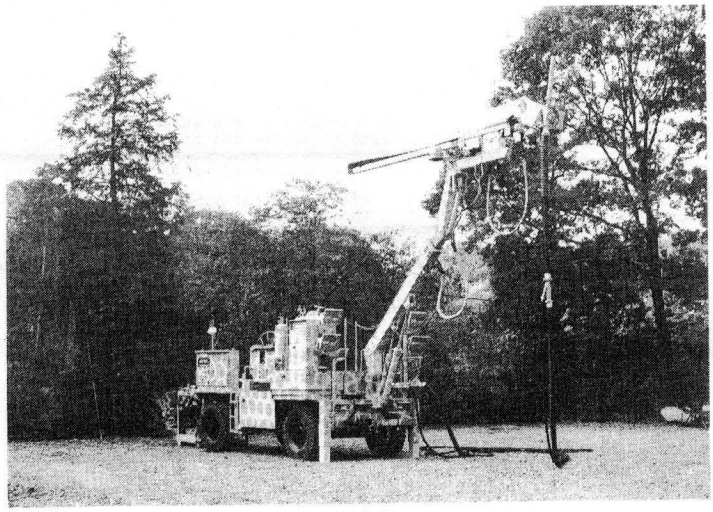


Fig. 5

6. SUMMARY

To sum up, this total control system for shotcreting is characterized by the following:

1) Labor-savings and automating of site control in shotcreting
The total control of "spraying robot," "concrete conveyer-pump," and "QSCA supply system" enables automatic shotcreting by data setting, such as the proper content of cement, the quantity of QSCA addition etc. and the like.

2) Excellent cost-effectiveness
This system, which reduces not only the rebound of shot-crete but also QSCA use by adding QSCA in the most proper ratio for the working area, enables more economical construction than ever before.

3) Homogeneous shotcreting
Using this system, homogeneous shotcreting is available by controlling the volume of QSCA addition in accordance with the measured height of the spraying area and the output quantity of concrete from the conveyer pump.

CONCLUSION

When this system was practically operated in two tunnel works, that is, the Sanyo-Motorway Mt. Kasai Tunnel-West and Aioi-Second tunnel-Second Section, it was proved to be useful.
Further, it was found to be of greater of effectiveness for the system, to use concrete of stable qualities, such as slump value and so on.