WALLCO ICOMA 70 rotary feed shotcrete machine dismantled for servicing during break in spraying operations.

Condition of the rubber gasket must be checked to ensure efficient operation of the machines.
Swedish shotcrete equipment and developments in fibrous shotcrete

By Claes Alberts \(^x\) and Maarten Kramers \(^x\)

The ROBOT

Background

At South Berwick, Maine (Bibl. 8) it was reported how the remote controlled spraying nozzle was developed to make it possible to spray over the muck pile when excavating a tailrace tunnel in Sweden.

Operation

On one of the basic designs the nozzleman works on a platform at the end of a long, truck-mounted boom which extends out over the muck pile. He operates a nozzle on the end of an extendable arm which provides a long reach. The nozzle is operated hydraulically and all movements are remotely controlled by the operator – this has been called the Robot method (Fig 1).

![Fig. 1 Robot shotcreting method](image)

Development

A number of important developments (Figs 2–6) have been made on the latest Robot models, for instance:

- the Robot is now equipped with its own advanced hydraulic system so that it can be easily put on whatever carrying system is available.

\(^x\) Claes Alberts, Managing Director, Stabilator AB, Stockholm

Maarten Kramers, Mining Engineer, MSc., Stabilator AB, Stockholm

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Fig. 2 Lorry mounted Robot R75 ready for transportation

Fig. 3 Robot R75, fully extended (note sliding platform)

Fig. 4 Control box for operating the Robot from any suitable place in the tunnel
**Fig. 5** The Robot-Trixer D 2800. A combined transportation, mixing and spraying unit.

**Fig. 6** The Robot-Trixer D 2850. Action range.

**Fig. 7** A Robot and Trixer unit mounted on rails for use in small tunnels in Peru.
- the basic sweeping movements of the nozzle are automatic, which makes it possible for the operator to concentrate on other essential factors.

- the Robot can be put on a platform with a well controlled lateral movement. This highly increases the rock area which can be quickly reached without moving the basic carrying truck (Figs 2, 3).

- All movements of the Robot are controlled from a control box which can be easily carried by the operator. This enables him to leave the machine and still control the whole operation (Fig 4).

- further developments have been made to combine Robot spraying with tunnel boring machines for a great range of tunnel sizes (Figs 9, 10).

Advantages for tunnel excavation

Robot shotcreting can begin immediately after blasting and ventilation (Fig 1). The hazardous and timeconsuming scaling operation can be avoided. The risk of a cave-in, triggered by the removal of key-stones is eliminated.

Overbreak is minimised which means a saving in support and lining, and also a better hydraulic efficiency of water tunnels where shotcrete is increasingly used as permanent lining.

In large tunnels the Robot makes it possible to muck and spray simultaneously, thus eliminating one distinct phase of the excavation cycle, earning a great deal of time.

A major strength of the Robot systems lies in its capacity to tackle and pass a cave fast and efficiently. The time available to stop a developing rock failure is short. If no immediate measures are taken to counter a cave-in at its initiation, it generally develops rapidly into dangerous
Fig. 8 The "Mini-Robot" for medium sized tunnels

Fig. 9 A fully automated unit used in the Heitersberg tunnel (Note double nozzle arrangement and rebound collectors).

Fig. 10 The control panel for the Heitersberg Robot equipment
proportions, ultimately closing off the tunnel. Without the Robot only elaborate, costly and time consuming measures are then left to reopen and pass such a collaps.

Advantages from the operator's point of view

The Robot operator works in safety, protected by the shotcrete layer applied after the previous blast. He is relieved from carrying the nozzle and the heavy material hose, and he is not working in a shower of rebound. Seeing what he is doing, at a safe distance from the nozzle, he can give all his attention to the systematic application of the shotcrete. Shotcrete quality is improved, rebound decreased. His job is also made easier by the fact that strong spotlights are fixed on the Robot and thus always directed on the right place. It is difficult to solve this problem when spraying manually without an assistant.

It has been clearly demonstrated, over and again, that when manual spraying is used the thickness of the resulting shotcrete layer at the roof section is much less than at the wall section. This is the logical result of the fact that shotcreting overhead is both bothersome and difficult, if not to say impossible even for an experienced nozzleman. The nozzleman can not see what he is doing because he can not look upwards when spraying. He tends to direct the nozzle obliquely towards the rock surface at the tunnel roof, thus increasing the rebound considerably. This part of the tunnel is therefore often dangerously neglected and can easily escape the observation of the inspectors.

When spraying by hand it is extremely dangerous and virtually impossible to treat large cave-ins or rockfalls under development. This is when an instant sprayed support is most called for: the Robot system gives a safe, efficient and rapid means of overcoming such difficulties.
The TRIKER

Background

The classical method of premixing the dry shotcrete has always been one of the weak links in the shotcrete process.

The premix procedure makes it difficult and often impossible to meet the deadline given in the specifications concerning the allowed age for fresh shotcrete.

The quality of the "dry" shotcrete mix (containing normally 4-6% humidity) decreases gradually after mixing. With the ever-increasing distance between mixing and spraying stations the loss of time for haulage may ultimately become prohibitive if a mix of acceptable quality is to be guaranteed.

Any foul-ups on account of a delayed blast, a mechanical breakdown, a derailment, a premature order or the like may result in the necessity of dumping the materials, when premixed. The risk of incidental use of a deteriorated, overaged batch does exist. Bad communications which often exist in tunnelling works, add to the problems.

The impact of the shortcomings of the premix method increases not only with the depth but also with the inaccessibility of the working faces and with higher temperature and humidity conditions.

These were some of the reasons why we felt we had to develop a better, foolproof transportation and batching system.

Operation

The Trixer transport mixer carries the cement and aggregates in separate compartments (Fig 11). Materials are mixed just before the actual spraying operation. The Trixers can therefore be kept ready for immediate operation at any location. They also give us the means to have a fresh dry mix, instantly available in any desired proportions. As the Trixer is
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designed for start-run-stop functioning, it produces always the exact amount of shotcrete needed. Over- and undershooting quantities and wastage of materials is avoided. Shotcrete quality is increased, as only fresh shotcrete passes the nozzle.

Fig. 11 The Trixer on a lorry chassis.

With the Trixer cement-aggregate mix proportions are instantly changeable to suit the local needs. It can be advantageous for instance to use shotcrete with a higher cement and accelerator content if there is sudden, local water infiltration.

Finally, when using premix procedures a mixing station has normally to be set up for each isolated tunnelsite. With the Trixer system only one unmanned material refilling station is required as one Trixer can service a number of fronts.
The **PROPORTIONING PUMP for liquid accelerators**

**Background**

There is a strong tendency to use liquid accelerators instead of powder products. This fact has been emphasized in some of the papers presented at this conference.

The change from powder to liquid has been primarily due to improvement of the ultimate shotcrete quality without sacrificing flash setting effects.

With liquids a smooth distribution and more even mixing of the dry mix and accelerator is obtained, and dust originating from handling and spraying powder accelerator is avoided. Liquid accelerators have also been developed which are less noxious than powders.

Clogging of the shotcrete equipment, and its subsequent increased wear and malfunctioning is prevented, as the liquid accelerator does not have to pass through the spraying gun, but enters the material line at the nozzle. This means that maintenance is held down to a minimum. Also undesirable setting action occurring between the moment of accelerator addition and passage of the mix through nozzle is prevented, thus improving the flash setting effect and increasing the shotcrete quality.

The main drawback of the liquid accelerator systems was the necessity to premix the accelerator with water to the desired strength and then transport this bulky premixed material to the working face.

**Development and Operation**

We therefore developed a small, lightweight double action pump that enabled us to bring together concentrated accelerator and water directly at the front (Fig 12). Moreover as the water-accelerator ratio is instantly changeable with this pump it gave us the means to adjust the accelerator concentration to the locally existing rock conditions.
Fig. 12 The EPN 3000 proportioning pump for liquid accelerators.

While no ingoing water pressure is needed, the outgoing line pressure can be regulated up to 15 kP/cm$^2$. The system can therefore be used where no water lines exist. The pump starts and stops automatically depending on whether the nozzle valve is open or closed.

The introduction of the accelerator pump has means an important improvement in standard shotcrete procedures.

STEEL FIBRE reinforced shotcrete - Nordforsk Research Programme

A large research programme on fibre reinforced concrete, has been carried out as a joint Nordic project (Nordforsk) with 12 participating research institutes and firms from Denmark, Finland, Iceland, Norway and Sweden. The report will be published in 1977. Stabilator AB has taken part with special interest in steel fibre reinforced shotcrete.

Within the scope of this development programme a full-scale test under site conditions was carried out during 1974. The test surface comprised 4,500 m$^2$ rough rock at a refinery at Brofjorden, on the west coast of Sweden.
We shall not go into details here as a special report from this work is going to be published in the main report. The test was made mainly to try out the mechanical equipment designed for the work and to give criteria for any necessary redesign or new design.

Despite the fact that the dry mix during these first tests only contained 0.7% by volume of fibres (l = 25 mm, d = 0.4 mm) the shotcrete layer has proved satisfactory. The alternative design comprised 70-mm reinforced shotcrete with joints every five metres.

On the basis of the experience from this and later works we have found that the Robot equipment described above is also suitable for fibre shotcrete spraying. An important addition is, of course, a fibre proportioning and dispensing unit (Fig 13). The one we used works on a mechanical raking and vibratory movement principle. The gun which has given best performance is of a modified rotor type.

Fig. 13 Mini-Trixer feed unit for fibrous concrete with dispenser and gun
At the same time as the practical tests were being made a series of separate tests were carried out on the fibre-reinforced shotcrete. Testing of the samples from this series was carried out at the Cement and Concrete Institute (CBI), Stockholm, which was also engaged in the whole Nordforsk Project.

Different types of fibre, different additives to reduce rebound, and the influence of cement content on the amount of rebound were studied and the following properties were investigated in detail:

- compressive strength, tensile strength, flexural strength, deformation properties and density.

The dry mix used was mainly 1:4 cement:aggregate by weight with material passing through a 16 mm (5/8") sieve. The best results were obtained with a wavey fibre, 20 mm long, 0.35 mm in diameter. The tensile strength of the fibre reinforced shotcrete increased by 50 % and the flexural strength by 180 % when compared to unreinforced shotcrete. Even the compressive strength was increased considerably, which is not so usual. The figures given here correspond to a fibre content in the dry mix of 2.3 % by volume, an amount which could be handled without any problems in the improved mechanical equipment.

Because the rebound of the fibres is greater than the rebound of the other materials the real fibre content in the test was much lower than in the dry mix and was calculated to be 1.34 % by volume.

Since these tests were carried out we have done a great deal of work to find methods of reducing rebound in general, and of the fibres in particular. The preliminary results show that the rebound can be reduced quite considerable by rather simple measures such as slightly reducing the speed of the material at the nozzle.
With the equipment described earlier for normal shotcrete using the Robot (remotely controlled equipment) one can obtain a highly mechanised and quick output, where scaffolding and fixed platforms for spraying can be avoided, even in high tunnels. But if one wants to reinforce shotcrete, for one reason or another, with for example a reinforcing net then new time consuming and handling factors come into play. Fibre reinforcement can be used here and save a lot of time, which is especially important for temporary reinforcement. Our opinion is that fibre reinforced shotcrete just for this reason will have a great importance in tunnel driving despite the relatively high cost of materials.

Bibliography


One property which has made shotcrete suitable for tunnel reinforcement is its relatively large ductility, especially during the first period after spraying. With fibre reinforced shotcrete this property can be greatly improved: "The greatest difference in behaviour of fibrous and non-fibrous shotcrete lies in the ductility or post crack resistance" (Bibl 10). That was also shown clearly by the Nordforsk tests (Fig 14).

![Load/deflection curves showing obvious strength improvements due to fibres](image)

**Fig. 14** Load/deflection curves, showing obvious strength improvements due to fibres.

A layer of shotcrete is often used as a protective coating to prevent waterflow and also to reduce the flow of air or other gases (such as radon). Here fibre reinforced shotcrete will be very useful as its high tensile strength and high flexibility will help prevent cracking.


