CONSTRUCTION OF HARD ROCK TUNNELS WITH REFERENCE TO THE KOTMALE PROJECT

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Since ages man has been constructing tunnels for various purposes. Today we have a wide range of equipment from which we choose the type that we find most suitable considering:

- Expected rock conditions
- Size of tunnel
- Length of tunnel
- Time available for construction
- Availability of experienced labour etc.
- The use of the tunnel
- Cost

In the early days only very primitive methods were used and very small resources were available. (Fig. 1)

FIGURE 1

Today we have mainly two major types of principles for excavation of hardrock tunnels:

- drilling holes to be charged with explosives
- full face drilling.

In Kotmale we have recently excavated 15 km tunnels and shafts plus 45,000m³ of rock cavern. The tunnels have been of varying cross sections from 6.5 - 75m². This of course requires that various types of plant, equipment and methods are used for the excavation.

In Kotmale for the tunnel excavations we have used the first method, i.e. drilling holes and using explosives. However, all shafts at the Project have been opened by use of raise boring equipment, which is a type of full face drilling developed for shaft excavation.

At the time of tender and planning for the tunnel excavation the Contractor normally has geological data indicating the prevailing rock conditions through which the tunnel is to be excavated. The designer has also decided to what size and shape the tunnel is to be excavated. Considering this information the Contractor decides how the tunnel is to be excavated. He will have to clarify the following:

- How far from the tunnel portal is the dumping area
- If it is a long tunnel, what advantages and disadvantages are there in constructing an extra adit to create further working fronts
- What type of plant is it possible to use in the tunnel considering its size and the rock conditions.
- Is the tunnel area suitable for only gallery excavation or is gallery plus bench preferable.

In a long fairly small tunnel the fullfacer could prove advantageous. The rate of progress between double-front, single-front and fullfacer excavation for various cross sections is compared in Figure 2.

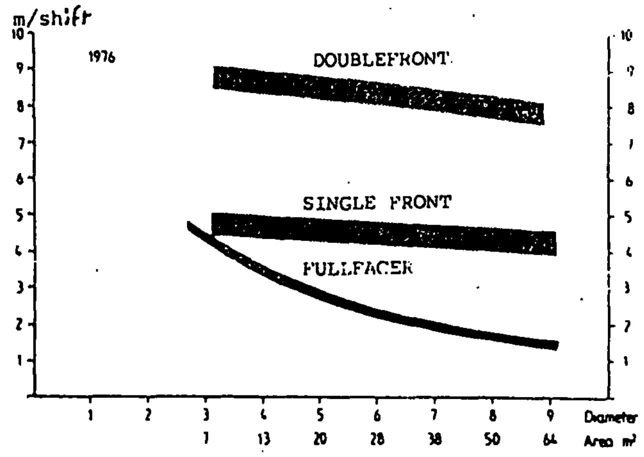


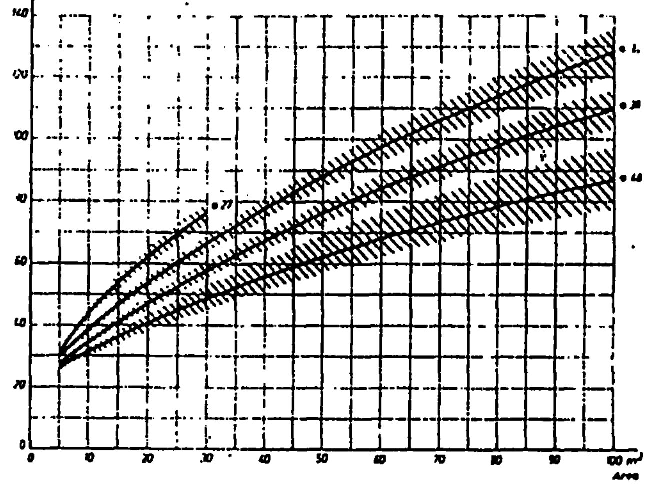
FIGURE 2

Using a full face drilling method you also obtain other effects like-

- smoother rock surface
- less disturbed rockwalls
- possibly less rock support
- less overbreak

If you choose a conventional excavation method by using explosives in drill-holes it has to be decided whether the holes are to be drilled by hand or by the use of a mechanised drill rig. Once this is done the number of holes in each round, drill pattern, type of cut to open up the round etc., are established. The number of holes depends on the cross-section of the tunnel as well as the diameter of the holes. See Fig. 3.

By using a drill jumbo, larger holes can be drilled thereby reducing the number of holes. The tunnels in Kotmale have been drilled both by hand and by drill jumbos. The Diversion Tunnels having a cross-section of 75m² have been excavated first as a gallery with a 40m² section and later on the section has been enlarged by excavating a further bench of 35m². This procedure is usually chosen when the size of the tunnel cross section is such that the available drill equipment cannot reach the full face to be excavated. Another factor could be that full face would require a large variety



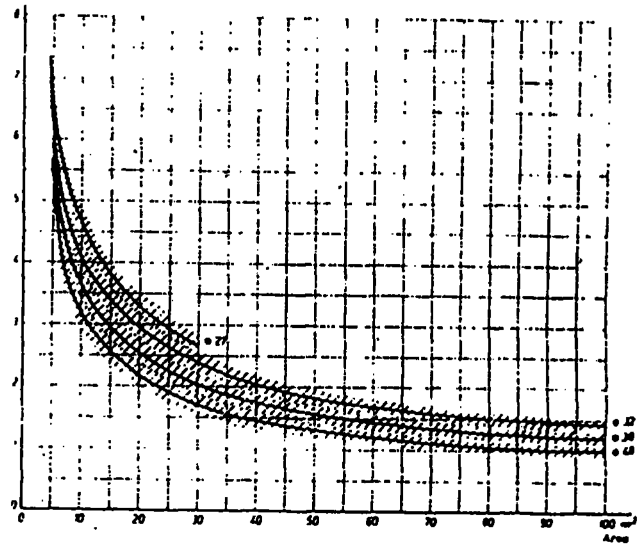


FIGURE 3

of ignition patrons giving different delays of the explosion not to cause excessive overlap of the pressure wave created by the blasting. It should also be pointed out that there exist different types of ignition systems:

- Fuse and detonator
- Electrical ignition
- Detonating Cord

The fuse is nowadays used very rarely and only in small blasts where electrical ignition is not possible. The electrical ignition is the most commonly used system today. This system has, however, some disadvantages such as:

- possible failure in wet conditions

- possibly effected by thunder storms

To overcome these problems the detonating cord, Nonel, was developed. The connector, which is an electrical detonator, is the only unit affected by electricity and water. This means a reduced risk for a missfire during charging caused by electrical ignition. For the underground excavation in Kotmale this Nonel detonator has mainly been used with a very good result.

Once the round in the tunnel has been fired and the blast fumes have been ventilated away the next phase in the cycle, the mucking, starts. The two major methods for mucking are:

- rail mounted equipment
- rubber wheel equipment

The rail mounted equipment is fixed to the tunnel and can usually not be used for other work elsewhere for shorter periods. Furthermore, tunnels sometimes have a gradient up to 1:7 either down or up and it is not possible to use rail mounted equipment on such steep slopes. If it nevertheless is deemed preferable to use this type of plant, a loading station has to be prepared inside the tunnel and more suitable plant will have to bring the muck from the loading station. For small to medium size tunnels, up to about 40m², equipment on rail is often used for reasons like-

- additional niches for loading, turning etc., are not required
- the possibility of having electrically operated equipment reducing the often very extensive cost for ventilation of the tunnel.

The seven kilometer long Low Pressure Tunnel at Kotmale has been excavated both from the Intake upstream and from a construction adit downstream. 4,200 m tunnel was excavated from the upstream with rail mounted equipment and 2300 m from the downstream was excavated by rubber wheel equipment. From the Intake one 1,500 mm ventilation tube was used and a total of three fans along the line were required. The rubber wheel tunnel required two 1,500 mm tubes and six fans along the line although it was only half the length.

In larger tunnels rubber wheel equipment of some kind is normally used and for the Diversion tunnels in Kotmale having a width of 9.2 m we used a Cat 988 for loading and Volvo Dumpers for hauling. The decision on type of equipment that finally is chosen sometimes depends on the possibility of alternative production during non mucking hours.

On completion of mucking of a round in the tunnel, it is inspected by the Foreman and/or other Supervisor. Sometimes support has to be applied before the mucking starts. If artificial support is required the decision has to be made at the tunnel face what type of support is to be used. Sometimes a combination of various support measures has to be considered. The techniques normally used are-

- shotcrete
- rockbolts
- pregrouting
- steel arches

The frequency to which the various methods are used in changing somewhat around the world, but is generally similar. In Scandinavia for instance we regard shotcrete to be a very useful support method and in other countries steel arches with backfill concrete might be preferred. However, it is the quality of the rock that will be the base for the decision which type of support is chosen but it is not always possible to state that this or that method is correct for a certain type of rock. Different methods might serve the same purpose.

The principle for rock support is either to tie the loose parts to more solid rock masses or to include the loose rock material in the construction of an arch which will be self supporting.

The most commonly used method is to install long steel bars into holes drilled into the rock and by this tie the rock together. The type of rockbolts can be classified into mainly two groups.

- tensioned bolts
- untensioned bolts.

Tensioned bolts are, when installed in the hole, fixed at the bottom of the hole and then tensioned to the load specified. By this the friction in the cracks and fissures is immediately increased which will prevent further movements in the rock. The anchorage in the hole can be achieved by expanders, wedges or by grouting using either cement or epoxy. The tensioning is mainly created by a nut at the threaded end of the rockbolt. The tensioned bolt is sometimes grouted in its full length.

Untensioned bolts are grouted to their full length and are in the initial stage without load. By a possible movement of the rock, a correctly installed dowel will take an increased load at the increased movement. The cement grout is inserted by various methods. One commonly used method is the Perfo method. A perforated tube split up lengthwise into two halves is filled with cement mortar and tied together to form a fully grouted tube. This tube is installed in the drill hole. Immediately afterwards the bolt is driven into this perforated tube and the cement mortar thereby fills up the hole completely. (See Figure 4)

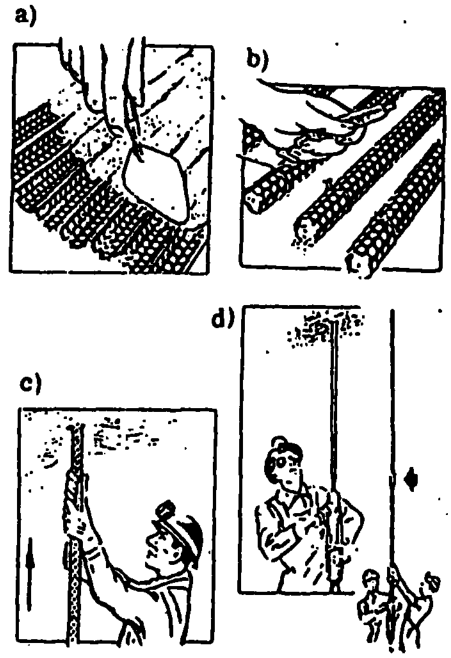


FIGURE 4

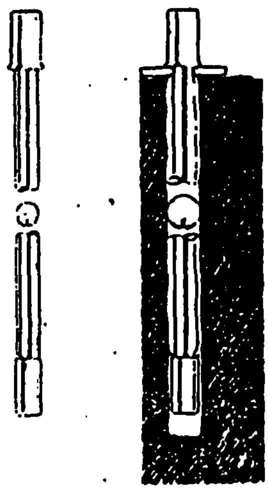


Figure - 5

In other methods the bolt is inserted into the hole and cement mortar is thereafter pumped via small hoses into the hole to its full volume. Special care is necessary when the holes are pointing upwards. In holes pointing downwards the cement mortar is sometimes only poured into the hole before the bolt is inserted.

The "Swellbolt" (see Figure 5) is a recently developed bolt mainly intended for drillholes less than 32 mm. It consists in principle of a steel pipe which has been deformed to a smaller diameter. When this bolt has been placed into the hole, water or air is pumped into the bolt which will then expand throughout its full length to completely fill the drill hole. This is a simple and very quick method and has been a big success in the Swedish mines.

Shotcrete can be applied using either-

- wet spraying
- dry mix.

The wet spraying, usually called guniting, is by use of a complete concrete mix sprayed under high pressure. For the dry mix shotcrete the water is added to the dry mix at the nozzle. This of course requires an experienced operator to get a good result. The effects from these two methods are, however, very similar. Even a thin layer of shotcrete has a considerable capacity of preventing rockfalls. It can be theoretically proved that a 30 mm layer of shotcrete can carry a load of 12 tons/m² provided good bond with the rock is achieved. It has also been demonstrated in several articles and it has been clearly demonstrated in practice that a shotcrete lining with minor deviation from a theoretical arch also provides a highly efficient support. A thin shotcrete layer, a mere skin, immediately after blasting can transform a rock of minor strength into a stable mass. The shotcrete lining does not generally support loads by transferring them to the tunnel floor as steel ribs do; it helps the rock to carry itself.

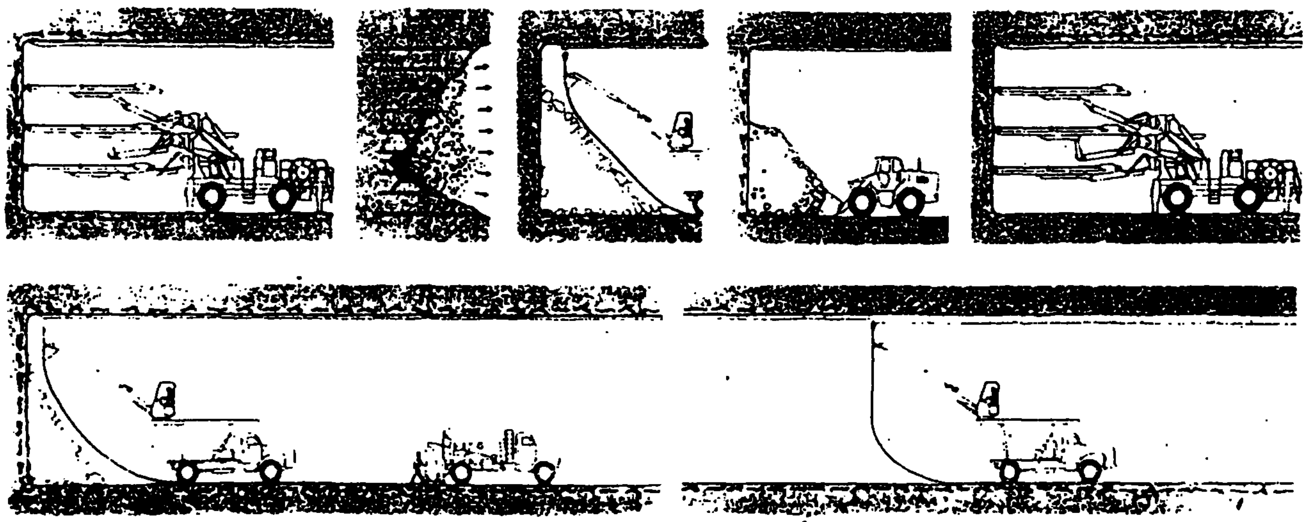
Skanska, or rather a subsidiary Stabilator, has developed a remote controlled shotcrete equipment called the Robot. They also developed a mixing unit for bringing the concrete aggregate and cement to the location to be shotcreted. By the Trixer-Robot system, which is usually lorry mounted, it is possible to have fresh material for shotcreting as well as the equipment prepared at all times and when required you can, within minutes, have the facilities brought into the tunnel. When very poor rock conditions have been encountered, the use of the Robot produces further advantages. (see Figure 6).

- spraying can be performed above the muck pile before mucking is carried out.
- the operator stays away from the danger area
- the operator is not physically tired from carrying the nozzle himself.

This shotcreting system has been used with great success in Kotmale and we have both lorry mounted and rail mounted Robots and Trixers.

Shotcrete is, like rockbolts, not only used for temporary support but also for permanent support, and as such it has been sprayed in the roof of the Machine Chamber and Surge in Kotmale and also in various access tunnels.

If, during the tunnelling, fractured rock with heavy water flow is encountered, pregrouting is a widely accepted



The working cycle of a tunnelling job.

FIGURE 6

support measure. In the Low Pressure Tunnel as well as the Grouting Gallery this method has been used. We have then drilled 18 m long holes in the surrounds of the tunnel, walls, arch and bottom, to fill the cracks, fissures etc with cement mortar to consolidate the rock and thereby reduce the water inflow. Once the water inflow has has been stopped, it is important that the tunnel is not advanced through the pregrouted area without investigating via pilot holes to make sure that further water cannot be expected. If there are reasons to believe that the water bearing section is continuing, the pregrouting should always be extended to a minimum of 6 m ahead of the face. This means drilling and grouting 18m ahead of the face, advancing the tunnel face 12 m, and repeating the procedure if required. By this the long term stability of the tunnel is also improved. There is always a risk that the water will transport some material from the rock mass and by this create the possibility for initial movements in the rock inducing an increased rockfall or possible collapse of the tunnel.

The use of steel arches is an often preferred method, especially to form a tunnel portal or when a collapse of the tunnel has occurred. The Low Pressure Tunnel in Kotmale has been supported over a short length by steel arches. Just before the tunnelling was completed, that is before the breakthrough, a fault zone of about 15 m width caused a rockfall in the tunnel. By use of steel arches back-filled by pumped concrete and further careful blasting, this section was successfully passed during a period of about two weeks.

The tunnelling works at Kotmale have been successfully completed.