EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
ORGANISATION EUROPÉENE POUR LA RECHERCHE NUCLÉAIRE

CERN - ST Division

CERN-ST-2000-029
February, 2000

VARIOUS TUNNEL EXCAVATION METHODS USED ON THE LHC PROJECT

R. Fielder

Abstract

Civil Engineering construction work for the LHC Project began in April 1998 and is now well underway. A major part of this work is the construction of the new tunnels, caverns and cavern enlargements for the LHC experiments and machine. Currently, this underground work is being carried out for the two injection tunnels, TI2 and TI8, and at Point 1 for the Atlas Experiment. There are three contractors involved in these tunnelling works and each contactor is using a different technique.
This paper will outline the different methods used for excavation and the reasons for these differences. It will also examine the other operations involved in the construction of major underground structures such as supply of materials to the tunnel face, evacuation of excavated material and ventilation.

Presented at the 3rd ST Workshop
Chamonix, France, January 25 - 28, 2000

1 INTRODUCTION

Civil engineering construction work for the LHC project began in April 1998.There are now four joint ventures of major European construction companies undertaking the civil engineering works. The contracts involve the construction of the new surface buildings and underground tunnels and caverns required for the LHC. To date, three of the contractors have begun to excavate below ground and it is this aspect of the work which my presentation will address. I will look briefly at the different methods used in construction and explain the reasons for these differences. I will also look at the various methods used for the supply and removal of materials and methods employed in the difficult task of ventilating the tunnels.

At the moment, underground excavation work is taking place at three different locations around the LEP ring; for tunnel TI2 accessed from new shaft PMI2, for tunnel TI8 accessed from new shaft PGC8 and for the underground cavern complex for the Atlas experiment at Point 1, accessed from new shafts PX14 and PX16. Owing to the different nature of the work at the different sites, each contractor is using different methods for excavation, removal of spoil, and supply of material to the face for the temporary lining.

2 POINT 1: CAVERN USA15

Contractor CCC are building the USA15 cavern at Point 1 using classic tunnelling techniques. Excavation has begun on the top of cavern USA15. This cavern is 13 m high and 20 m wide. The sandstone rock is excavated using a tracked machine similar to those you would see on any surface construction site. It is equipped with a hydraulic rock breaker which smashes the rock into long, thin sections. The size of the cavern allows fairly free movement of vehicles during construction. The excavated rock can therefore easily be collected by a vehicle called a ‘boomer’ which takes it to the shaft for removal to the surface.

The materials required for the construction of the temporary support lining are also brought in by vehicle. The materials required are rockbolts, steel mesh and dry shotcrete. Shotcrete is a special type of concrete which is sprayed at high pressure to form the shape of the excavated surface. In this case, it is pumped dry to the face where water is added along with an additive which sets the concrete at a much faster rate than normal. The first activity following the excavation is to spray 10 cm of fibre-reinforced dry shotcete on to the exposed rock. The fibres are steel and look much like large staples. They add tensile strength to the shotcrete. After this first layer of shotcrete, a second layer 5 cm thick, but containing no fibres, is sprayed. Around the excavation, the rock is weakened by the excavation process and these layers of shotcrete are not strong enough to support the rock in the long term. Sandstone will normally support itself for some time, but will then start to collapse. Therefore, a steel mesh is moulded to the shape of the cavern to provide additional stability and rock bolts are then placed to tie the weak, unsupported rock back to the undisturbed rock behind. The holes for the rock bolts are drilled up to a depth of 9 m using a specialized drilling rig, which can drill two bolts at a time. The bolts are fixed in place by injecting a cementitious grout at pressure around the bolt to secure it to the rock. The disadvantage of this system is that the work has to be stopped to allow the grout to set. Although slow, this process is used because the materials are cheaper than the faster systems which will be examined later

3 SITE DE MEYRIN: TUNNEL TI2

A similar method is being used by contractor TWASB for construction of tunnel TI2. This is the clockwise beam injection tunnel. It is approximately circular in shape with an excavated diameter of 3.8 m and a cross-sectional area of 11.4 m^2. This tunnel is being excavated in two directions from the centrally located shaft PMI2. Towards the LEP the tunnel is 1125 m long and towards the SPS it is 1523 m long. It is being excavated using a machine called a road header. This is a tracked vehicle similar to that used in the cavern USA15 but modified for tunnel works. One major modification is that it runs from an electrical power supply to reduce the dangers of pollution at the face. It excavates using a rotating drill head mounted on the end of a pivoted boom.

This method of excavation is well suited to the hard but brittle sandstone rock through which the tunnel is being excavated, the teeth tearing blocks of rock out of the face. However, it does have the disadvantage that it creates a large amount of dust, a problem we will look at later.

Once the rock has been excavated, it has to be removed from the front of the machine and taken out of the tunnel. As is common with most machines of this sort, this is done by metal scoops which pull the spoil to the centre of the machine where it is picked up by a conveyor belt which transports the spoil to the back of the machine. From the back of the machine conveyors again take the spoil all the way back to the shaft. Conveyors are used in this case as the size of the tunnel does not allow vehicles to pass. Towards the LEP, the tunnel is 1523 m long and therefore if only one vehicle was allowed in the tunnel at any time, it could take up to 5 minutes to make the journey from the face to the shaft and back. This would not be fast enough to keep up with the excavation rate, leading to a reduction in the rate of advance.

Materials required at the face for lining the tunnel include rock bolts, steel mesh and steel arches. These obviously cannot be transported on a conveyor and so are delivered by dump truck or loader. Concrete is also required and in this tunnel it is stored wet at the bottom of the shaft and pumped to the face when required where again a chemical which accelerates the setting process is added.

Even in a small tunnel, the excavation process weakens the rock in the area around the tunnel. In weak ground, where disturbed rock may fall before the lining is constructed, wire mesh is placed against the excavated surface to protect the men working below. A 5 cm thick layer of fibre-reinforced wet shotcrete is then sprayed over the whole of the exposed rock face to stabalize any loose fragments of rock. Since the rock close to the tunnel has been weakened, bolts up to 2.5 m long are drilled into the rock to tie this weak rock to the more stable, undisturbed rock further away from the excavation. In this tunnel the bolts are not grouted in place but ‘Swellex’ bolts are used which are mechanically expanded to grip the ground. These bolts are actually hollow steel tubes which have been compressed in the factory to reduce their diameter. Once in place, these bolts are re-expanded to their original size using highly pressurized water to grip the surrounding ground. These bolts are used because, although expensive, they support the rock as soon as they are expanded, unlike the grouting method examined earlier. They enable other activities to be carried out immediately after the bolts are placed and so allow constant production. A further layer of fibre-reinforced shotcrete 5 cm thick is then sprayed over the top of the bolts and allowed to set before 5 cm of plain shotcrete is sprayed to finish the lining.

4 TUNNEL TI8

The final example of tunnel excavation on the LHC project is the construction of tunnel TI8, the anticlockwise beam injection tunnel, from shaft PGC8. In the direction of the LEP this tunnel is 2285 m long, and towards the SPS 172 m. Towards the SPS, a roadheader is used as for TI2. However, towards the LEP the tunnel was long enough for contractor ATIC to propose construction using a tunnel boring machine (TBM). TBMs are expensive to install (a new machine, with all the back up equipment, might cost CHF 7 million) and require a large amount of backup machinery. However, they can excavate at much higher rates than the machines we have seen used by the other contractors and are safer as they often contain a shield, a metal drum which protects the workmen from falling rock. For these reasons a TBM is the preferable method of excavation for long tunnels.

Since this tunnel is being excavated by a machine which is circular, the tunnel itself is circular with an external radius of 3.6 m.

Excavation of rock on this machine is carried out by the cutting discs mounted on the front of the machine. The whole head of the machine rotates as it is forced into the ground ahead by hydraulic jacks. This is called a full face machine as the whole face is excavated at the same time.

As in tunnel TI2, the size of the tunnel limits the use of vehicles in the tunnel, so excavated material is taken to the back of the machine using a device like an Archimedes screw before the rest of the journey to the shaft is again made on a conveyor.

The supply of materials to this TBM is made by a small train running on rails which are placed behind the machine as it advances. Here again the construction of the support lining is made in the same way as the TI2 tunnel. There is one difference in that the ground encountered has been much weaker than at first expected and has collapsed on several occasions before the machine has moved far enough to permit construction of the lining. Therefore a more rigid support has been used involving steel arches and steel plates, which are used to support the rock before the shotcrete and rock bolts are installed.

5 VENTILATION

A major problem on all tunnelling sites is the provision of ventilation to those working on the excavation. The nature of the limestone rock in which the new LHC tunnels are being constructed does not help as it breaks very easily into a fine dust. The spraying of shotcrete also causes a large volume of dust. The first priority is to protect the men carrying out the work. The dust must be removed from the air in the tunnel as soon as possible, and water is frequently sprayed from the boom of a road header to reduce the dust content in the air. The air is generally sucked back down the tunnel and up the shaft in flexible pipes. However, it cannot be released straight into the atmosphere as this would cause ecological problems. The dust is therefore removed from the air by passing it through a deduster. This is normally achieved by bubbling the air through water, before releasing it into the atmosphere.

6 CONCLUSIONS

There are various methods of excavating tunnels and caverns. The choice may depend upon the nature and size of the structure to be constructed, the type of ground or even the machinery available to the contractor. There is also a balance between the speed of the work and the cost, and again the methods used may often be governed by the time available and not by a desire to minimize the costs.

The three LHC sites examined give a good illustration of the various methods possible, as all of the sites use different methods for excavation and support of the tunnel.

Future developments in tunnelling are obviously limited by the fact that, at the moment, there are very few methods of excavating hard rock in a confined environment. However, improvements can be made in the quality and strength of materials and even the methods of constructing the lining. The latest TBMs are designed to run automatically and they even extrude a fast setting concrete lining just behind the excavation. This brings improvements in safety and rates, but is expensive.