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**THE LARGEST FULLY LINED BLIND BORED VENTILATION SHAFT CONSTRUCTED TO  
DATE IN AUSTRALIA**

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# **BLIND BORE SHAFT METHOD, SUCCESSFUL COMPLETION OF THE SOUTHERN COALFIELDS VENTILATION SHAFT**

## **ABSTRACT**

The Blind shaft boring method is a mechanised process of excavating large diameter vertical shafts downward from the surface. It is a rotary drilling technique eliminating any requirement for personnel to enter the shaft or access underground workings during drilling and lining phases. Excavated material is delivered to surface carried by a flow of circulating fluid through the centre of drill rods. The drill assembly is suspended from a large A-frame rig and powerful winch at ground level providing vertical thrust to a hard rock cutter head.

## **KEYWORDS**

Blind Shaft Boring Method, Blind Bore, Mechanised Process, Eliminates, Shaft, Rig, Drilling Shafts

## **INTRODUCTION**

The Southern Coalfields Ventilation Shaft was constructed at a mine, 45 km north-west of Wollongong. The 5 m finished diameter (6.2 m drilled) shaft reaches a final drilled depth of 517 m, the deepest, fully lined blind bored vent shaft to date in Australia.

Operated by a mining company in the Southern Coalfields, the expanding mine required a new ventilation shaft and associated surface infrastructure to service future operations.

An assessment of future ventilation requirements for the coal seam operations identified a need to improve the capacity and reliability of the existing underground ventilation system in order to ensure a safe and efficient underground working environment. Installation of the new upcast ventilation shaft was determined to be the most cost effective and reliable solution to provide adequate ventilation for underground operations.

The completed shaft is smooth and fully lined with steel/concrete composite liners that are hydrostatically sealed. The shaft lining is designed to meet the mine ventilation requirements for a service life of 20 years.

The shaft intersects the top of the working section of the coal seam at approximately 513 m of depth. This includes the shaft collar depth and shaft bottom profiled intake section.



Figure 1. Job site

### **PROJECT METHODOLOGY AND INDUSTRY BEST PRACTICE**

The shaft was drilled using the blind bore method, an innovative construction technique and an alternative to the traditional methods of sinking deep and large diameter shafts, such as raise boring and conventional drill and blast shaft sinking.

The blind bore method allows the shaft to be drilled from the surface down without anyone having to enter the shaft or the mine during the construction process. This is by far the safest method of shaft construction and is especially suitable for difficult ground conditions where there may be unstable or water-charged strata.

As this method involves drilling from the surface downward, shafts can be completed ahead of the underground mine development. Thus, allowing underground operations to focus on development and production without the conflicts of managing ventilation priority for underground contractors and mucking out spoil from excavation workings.

### **SCOPE OF WORK**

The scope of work for the shaft consisted of the following major activities:

- Survey and set out.
- Preparing and maintaining the construction site including the sedimentation (or spoil settling) ponds.
- Design and construction on site of shaft linear segments for the full depth of the shaft but excluding the shaft bottom profile intake section.
- Design, excavation and construction of a reinforced concrete shaft collar.
- Design and construction of blind bore drilling rig foundations and footings.
- Set up and maintenance of blind bore drilling rig equipment to suit the operations.
- Excavation of the ventilation shaft between the base of the collar and top of the coal seam but excluding the shaft bottom profiled intake section.
- Installation of the site constructed composite steel and concrete liner segments to provide a fully hydrostatic liner.
- Removal and disposal on the site of all shaft spoil in accordance with approved procedures.
- Dewatering the shaft at completion.
- Temporary construction of site facilities including offices, personnel amenities, first aid facilities, storage compound, safety fencing and signage.

- Supply and maintenance of construction services, including potable water and compressed air.
- Site clean-up upon completion of works.
- Documentation of management and maintenance procedures.
- Supply of specified documentation and “as built” information.

## PROJECT PHASES

### Shaft pad and collar

Construction of the shaft commenced with construction of the shaft pad, collar and pre-sink. The shaft collar, pre-sink and pad provide stability to the ground at the top of the shaft to support the drill rig and to provide a base for the vent elbow.

The collar was constructed by first creating a 7 m diameter by 9 m deep excavation, installing a 9 m deep pre-sink liner concreted into place to form a 6.2 m diameter shaft collar.

### Rig assembly

Upon completion of the shaft collar and pad, the drill rig was assembled on the pad. The drill rig consisted of a 450 tonne lifting capacity A-frame. The rig’s winch was powered by 2 x 450kW hydraulic driven motors. The drill head was driven by four hydraulically powered motors driving a final drive helical gear.

The drill head consisted of cutting discs arranged in a hemispherical profile cutting head assembly. The cutting discs are not powered but rotate as the drill head is rotated due to friction of the strata on the discs. The drill head rotated at approximately 3 rpm. Controlling the winch and drill head motors by variable speed drives provided precise control over torque, rotary speed and thrust.



Figure 2. Installation of pre-sink



Figure 3. Raising the drill rig

### **Shaft excavation (drilling)**

The shaft was excavated using blind bore rotary drilling. The rigid large diameter drilling assembly was stabilised at two points to control deviation to within half a percent of depth.

The drilling head assembly (DHA) was heavily weighted to provide vertical thrust to a hard rock cutterhead equipped with disc type cutters. The disc cutters ground a series of concentric grooves into the rock face, leading to fragmentation of the rock between the cutter paths into relatively large pieces. In the later stages of the drilling phase the rock cutters were replaced with tooth cutters to address specific strata issues during excavation (see more in Challenges with drilling).

During all phases of the shaft drilling and lining process, the shaft remained filled with water to within a few metres of the surface. Water in the shaft helps with a number of things. Water provides counter pressure to contain naturally occurring aquifers, oil or gas that might be encountered within the strata. It enables the reverse circulation process to work, extracting rock cuttings from the face to the surface. Additives can be added to the water to combat problems with shaft sidewall stability. On this project, bentonite as well as clay inhibitors were added to aid in preventing side wall failures.

The water also allows permanent shaft linings to be installed and grouted under pressure. A balance or slight overbalance with the naturally occurring pressures in the ground eliminates water flow from the strata into the shaft that could otherwise wash away the cement grout.

### **Reverse circulation**

Whilst drilling, rock fragments were transported from the face to the surface by a strong flow of water directed around the cutterhead and up through the centre of the drill rods before being discharged into the circulation ponds on the surface. Negative pressure was induced in the drill string by injecting compressed air via a small diameter air tube resulting in pneumatic lift and reverse water circulation causing the cuttings to be discharged into circulation ponds at the surface. After sufficient sedimentation time to allow the solids to fall out of the water, the water was then returned to the shaft by a return water pump to complete the circulation system. Figure 5 shows the discharge hose from the top of the drill string into the circulation ponds.

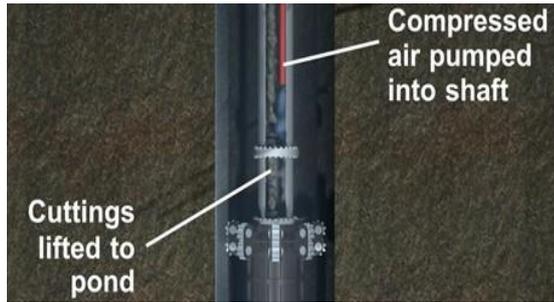


Figure 4. How pneumatic lift is created in drill string



Figure 5. Hose discharging spoil into circulation pond

### Challenges with drilling

Difficult strata conditions presented complex challenges for the Abergeldie project team. Whilst drilling through the Bulgo sandstone found between 230 m–422 m the drill rig began to rock and bounce around more than usual. Based on rock samples recovered on top of the DHA and advice given by a Geotechnical Engineer it was determined that there was sizeable material coming away from shaft wall as a result of stress relieving.

The material coming away created voids in the shaft walls, preventing the DHA's lateral stabilisers from working effectively. This increased the rate of wear on the DHA cutters reducing the drilling penetration rate and also led to damage of the stabilisers when contact was lost with the wall of the shaft.



Figure 6. Process water in large circulation pond with drill rig

Large pieces of material fell down from the shaft walls towards the drilling face and those that did not come to rest on top of the drill head were very difficult for the cutters to break up into fragments small enough to be removed by the reverse circulation process. The large fragments tended to build up around the cutters as they tried to work their way down the drill head towards the evacuation point at the tip of the drill head holding the DHA back from the excavation face and inducing additional torque. Like marbles rolling around on a smooth floor, the fallen rock would simply be pushed around and moved out of the way of the cutters, rather than being broken down. Figures 7a–7d further illustrate the difficulties encountered.



Figure 7. a) Rock debris recovered on drill head; b) Large unprocessed rock material recovered from circulation ponds; c) size of large rocks recovered in dams; d) damaged stabiliser tyres caused by loss of wall stabilisation resulting from voids in shaft walls

Once the effects of shaft wall voids on the drilling process were understood, the project team began to develop an alternative methodology to deal with the specific strata conditions encountered. To counteract the loss of stabilisation and improve cleaning of the fallen material from the shaft floor, tooth cutters were installed on the cutter head. The tooth cutters provided a larger, more stable, platform for the DHA working like a sheep's foot roller in breaking up the loose material.

Although this methodology allowed the work to continue, the tooth cutters did come with two major disadvantages when compared with the disc cutters previously used.

1. The tooth cutters had a significantly reduced penetration rate and higher wear rates than disc cutters in rock of the strength the team encountered on site.
2. The tooth cutters also produced a substantially larger amount of fines within the drilling fluid in the excavation process whilst breaking up the fallen material. The increased fine content in the drilling fluid further reduced the capacity of reverse circulation system to clean the floor. This caused the material to be reprocessed even further producing even more fines which were excessively abrasive on the cutters. Fortunately, the project team came up with a way of treating the process water to bring the suspended solids content down (more on this in Innovations During The Project).

### Shaft verticality

On completion of shaft excavation, a survey was carried out on the shaft to confirm the final drill depth and verticality of the shaft prior to installing the shaft liner segments.

The vertical alignment of the shaft centreline did not vary more than 0.75% of the depth from the true vertical shaft centreline at any location.

### **Shaft lining**

Once the shaft had reached the intended total depth, the shaft was lined with the steel reinforced concrete composite liner sections. When fully installed this liner method provides a high quality, smooth concrete and fully hydrostatic lining that will add to the life of the shaft and reduce the maintenance of any ventilation fan arrangement mounted on top of the shaft. All work to manufacture the 170 liner segments occurred at the shaft site to avoid additional transport costs and so the quality of each segment could be controlled and assured. The composite liner was terminated at the top of the coal seam.

The installation of the liner was a technically complex process involving the fitting of a 'stem' of liners weighing in excess of 8,000 tonnes. As the lifting capacity of the drilling rig was limited to 450 tonnes, the liners were installed from the surface by 'floating' them into the water filled shaft. This involved first placing a liner full of concrete (known as the plug) into the shaft and sequentially welding liner segments on top of the stem, keeping the inside of the liner stem dry, and progressively lowering the liner stem into the shaft until the buoyancy of the liner stem caused it to float. By then carefully placing calculated quantities of water into the liner stem as the remaining liner segments were added, the balance of hydrostatic pressure kept the weight on the rig at around 150 tonnes, whilst the full 8,000 tonne weight of liner segments was installed to the full depth of the shaft.

Once the shaft lining had been installed and grouted, the plug was drilled out and the water was removed from the shaft. Testing with a piezometer from the shaft surface confirmed there was no water left in the shaft at the conclusion of the bailing operation.



Figure 8. Liner Installation



Figure 9. Setting up to cast the liner into position prior to bailing out shaft

### INNOVATIONS DURING THE PROJECT

During construction, dirty process water was passed through a series of treatment processes and circulation ponds. Normal practice is for drilled spoil to be brought to the surface as suspended solids using reverse circulation to be discharged with the process water into the circulation ponds where the suspended solids are allowed to settle to the floor of the ponds. The water is reused in the shaft in the closed loop reverse circulation process, however, the use of tooth cutters on this project produced a substantially larger amount of fines within the drilling fluid in the excavation process particularly whilst breaking up the spalled material. This caused the material to be reprocessed even further producing even more fines, resulting in process water containing over 115,000 mg/L of suspended solids. These extremely fine particles had colloidal qualities and would not settle to the bottom of the recirculation ponds.

The suspended solids needed to be brought down from 115,000 mg/L to < 50 mg/L so that the process water could be reused again and again as boring proceeded.

The sites EPA licensed conditions for water quality were:

- pH 6.5–8.5
- Electrical conductivity < 302.5  $\mu\text{S}/\text{m}$
- Turbidity < 50 NTU

After many months of painstaking trials of several methods to treat the 18 million litres of drilling process water to reach quality acceptable for discharge, the project team adopted a very effective process. The water treatment process involved injecting a flocculant solution into the drilling water upon entering a centrifuge. The flocculant solution when mixed with the drilling water attracted the smaller suspended solids to form larger clumps which were then removed by the centrifuge.

This treatment process solution was highly effective at reducing turbidity levels to below the discharge limits. Figure 10 illustrates the process water before and after the treatment cycle.



Figure 10. Process water before and after treatment

### **ENVIRONMENT**

Approximately 100 tonnes of steel was recycled from the project. All waste oils were recycled and all drilling process water was treated to stringent environmental standards to meet the sites EPA licence conditions for water quality.

### **TIMING**

The project team commenced on site April 2012 with site survey and set out, pre sink construction and construction of the liner manufacturing zone. Drilling commenced 14 December 2012 and the shaft reached its target depth on 18 November 2014. Lining took just over a month, beginning 29 November 2014 and finishing 6 January 2015.



Figure 11. Drill rig with drill head raised