Freeze drilling keeps Hallandsås on track

Thomas Teer and Dan Billig of Prime Horizontal reveal how freeze-hole drilling was used to support the weight of a TBM in poor ground in the Hallandsås

THE Västkustbanan rail line, running between Gothenburg and Malmo, is one of Sweden's most important, linking rail transport between Norway and Continental Europe. Still undergoing modernisation, more than 80% of the line has already been upgraded to double tracks. But, since 1988, the main bottleneck to its completion has been the 8.6 km stretch of track running in two, parallel tunnels through the Hallandsas ridge between Båstad and Forslov in Southern Sweden.

The story of the Hallandsas Rail Tunnel is testimony to the technical skill and innovation required to complete a project that is hailed as the most technically complex tunnelling project in the world, currently scheduled for completion in 2012.

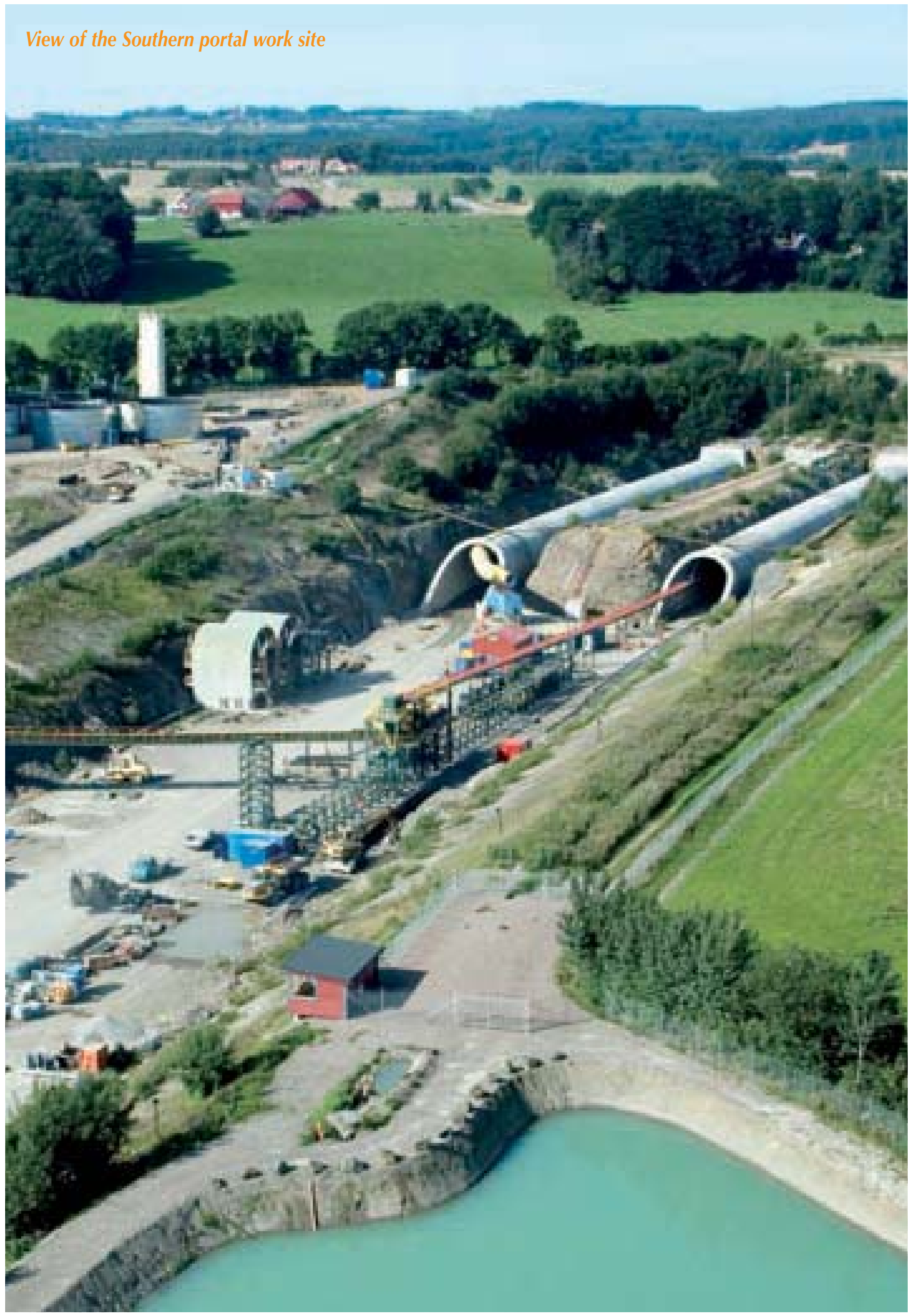
Swedish-French consortium Skanska-Vinci took over the project in 2002 and the final drive to completion began in 2004 with a purpose-built, 240 m-long TBM. Nicknamed Åsa and built by Herrenknecht, this TBM controls the ingress of copious amounts of groundwater under high pressure, up to 13 bar, and also bores and seals the tunnel.

The development of this TBM removed one of the largest challenges in boring the Hallandsas tunnel, leaving one major bottleneck – boring through a 30 m-thick zone of unconsolidated sandy silt and gravel within the Molleback Zone of the Hallandsas Horst.

GEOLOGY

The Hallandsas Ridge is a geological horst, composed of metamorphic, Precambrian rock, flanked on the north and south by later sedimentary rocks. In the vicinity of the tunnel, the horst is 8.6 km wide and rises to elevations of 150-200 m. Several major faults lie within the horst and there are also many intrusive dolomite dykes.

Drilling in the Hallandsas horst is characterised by the production of large volumes of water under high pressure. This causes the problem of flooding, as well as allowing sealing grout and cement that was introduced during the tunneling process to travel to the surface. The development of the Åsa TBM has solved these problems by controlling this water in an environmentally-friendly manner during tunnel boring. ➔



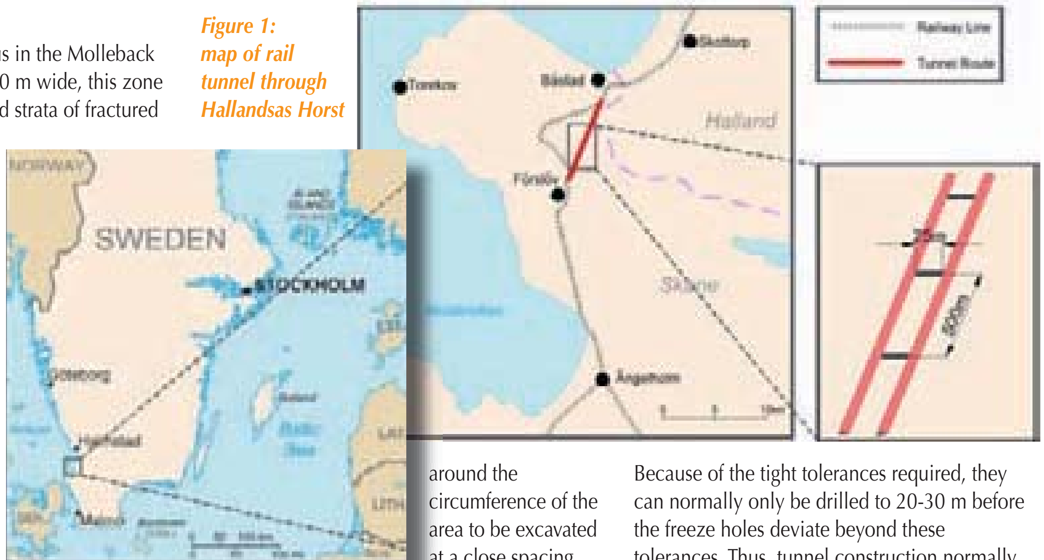
View of the Southern portal work site

PROJECT: Hallandsås Rail Tunnel

MOLLEBACK ZONE

Flooding is especially serious in the Molleback Zone near Båstad. About 300 m wide, this zone consists of vertically-oriented strata of fractured rock, which contains a 30 m-wide vertical fracture zone of very poorly-consolidated sand and gravel, with communication to the surface. The water saturation in the Molleback Zone was mapped with a resistivity survey in 1999 and the low resistivities, shown in figure 2, directly correlate with high volumes of water.

Figure 1: map of rail tunnel through Hallandsas Horst



FREEZE DRILLING

While TBM Åsa solved the tunnel-boring problems in the rest of the Hallandsas horst, this soft, 30 m zone could not support the weight of a TBM, as was discovered in previous attempts using a different machine. The solution was formation consolidation using freeze-hole drilling techniques.

Freeze-hole consolidation involves the freezing of a soft or water-saturated formation using an arrangement of boreholes similar to that used in a standard grouting procedure. The main difference is that freeze holes are located only around the circumference of the area to be excavated at a close spacing, such that when the freezing brine at a temperature of - 40° C is circulated, the surrounding formation will be entirely frozen between each freeze hole.

The exact position of the boreholes is critical to provide a uniform cover of consolidated ground since any gaps in a structure supporting hundreds of tons of silt and water under pressure would be absolutely catastrophic.

Conventionally, freeze holes are drilled in a straight line without using special techniques to correct their natural deviation from this path.

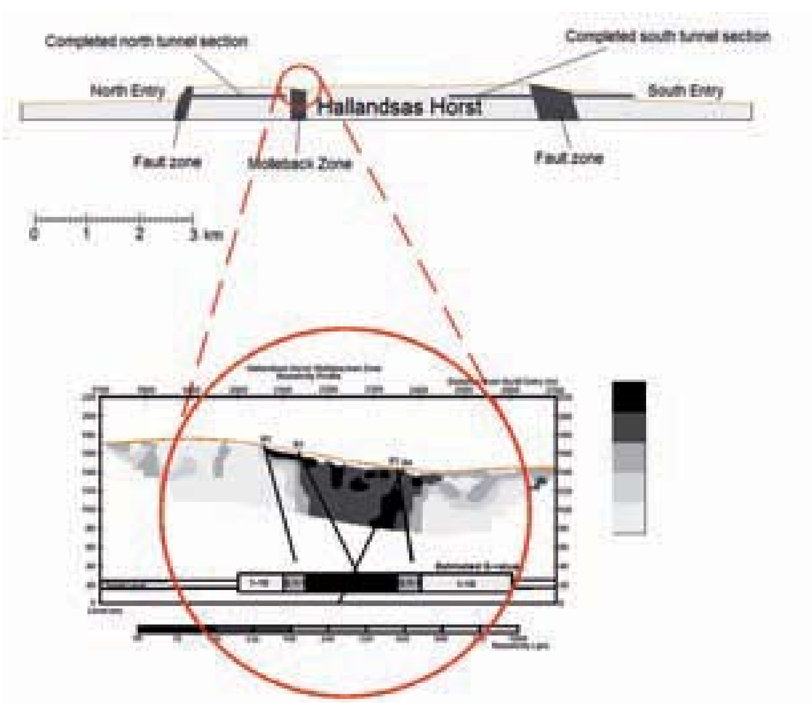


Figure 2: cross-sectional view of the Hallandsas Rail Tunnel. The inset shows a black/white scale of measured resistivities, where black indicates low resistivity ranges and white indicates high. The low resistivity of the Molleback Zone indicates the presence of large amounts of water. Data is provided courtesy of Dahlin., T., Bjelm, L. & Svensson, C. (1999)

Because of the tight tolerances required, they can normally only be drilled to 20-30 m before the freeze holes deviate beyond these tolerances. Thus, tunnel construction normally proceeds in 20-30 m sections.

In the case of drilling through the Molleback Zone, the conventional method of drilling 20-30 m sections was unsuitable because a considerable thickness of solid granite had to be left as a natural barrier between the tunnel face and water-saturated silt zone to avoid tunnel collapse.

For safety, it was decided that a drilling distance of 69 m should be left between the tunnel face and silt section. Adding this safety factor of 69 m to the 30 m of silt section that the boreholes would have to pass resulted in a total bore length of 99 m (as shown in figure 3); more than three times the conventional freeze-hole length.

Since the accuracy of the boreholes along this 99 m route and within the silt section were of paramount importance, the drilling tolerances were very tight. Each freeze hole was not allowed to deviate more than 50 cm from the proposed bore over its 99 m length. The freeze-hole configuration shown in figure 4 extends 99 m into the formation.

Prime Horizontal was subcontracted by Micon Gmbh to perform the guidance of the drilling of the freeze holes. To compensate for the longer than normal holes, Prime adapted a guidance technology that is usually used for drilling parallel oil wells.

Developed by Vector Magnetics and licensed to Prime Horizontal for use in the HDD industry, the Rotating Magnet, part of the ParaTrack HDD guidance system, uses a magnet of known strength, placed behind the drill bit. This magnet is rotated past a steering tool that is placed in a sacrificial borehole, which senses the magnetic signal received from the rotating magnet. From this data, it computes the position, heading and inclination of the drill bit, thus giving the drilling engineer sufficient information to keep the drilling process on the planned track.

PROJECT: Hallandsås Rail Tunnel

"Through the Molleback Zone, the conventional method of drilling 20-30 m sections was unsuitable"

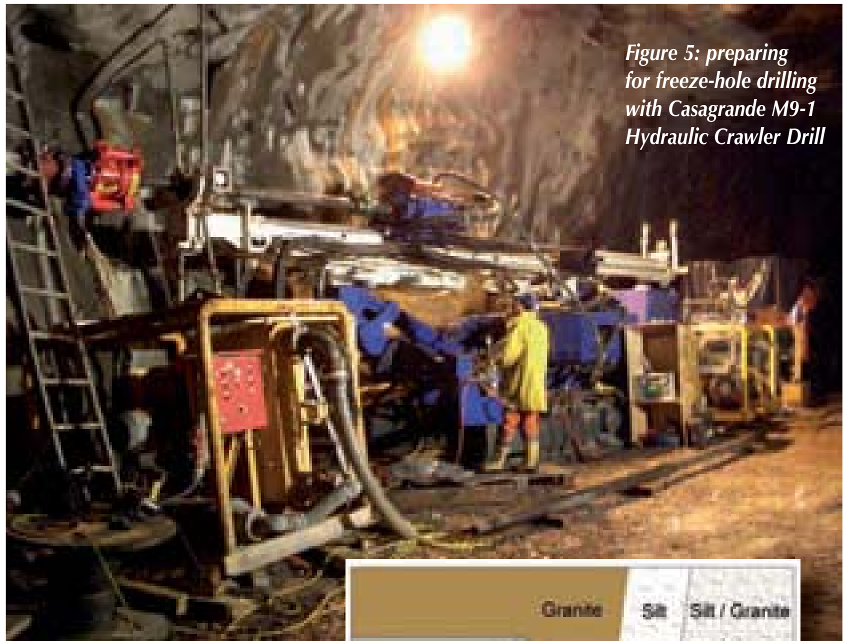


Figure 5: preparing for freeze-hole drilling with Casagrande M9-1 Hydraulic Crawler Drill

To drill the freeze holes, a standard mud motor was used, with a 1.8° bend at the drill bit end, orientated to make any necessary corrections to the steering.

Extensive testing took place in both the Micon workshop in Germany and Prime Horizontal workshop in the Netherlands, where it was determined that the Rotating Magnet had the range, accuracy and reliability to complete the project.

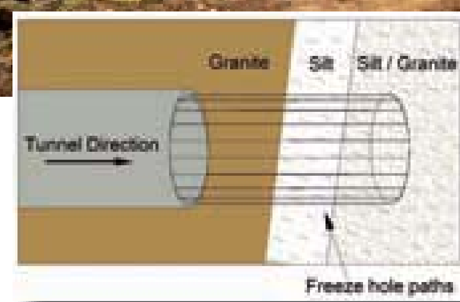


Figure 3: the planned 99 m zone for freezing (not to scale)

OPERATIONS

Most of the problems encountered while drilling were due to the soft and pressurised nature of the silt formation. Frequent hole collapses and washouts caused steering problems, which were overcome by grouting the washed-out area with an environmentally-friendly product and then redrilling through the affected area.

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PROJECT: Hallandsås Rail Tunnel

View down the 240 m-long mixshield TBM

"Freeze-hole drilling began at the end of August 2005 with two 12-hour shifts by Prime and DDS... operations ran around the clock... until the end of January 2006"

This localised grouting proved to be effective for a small area, but it was considered that, given the condition of the formation, any attempt to consolidate a larger area would prove expensive and ineffective.

As with any system that relies on magnetic field strength, guidance was affected by local, magnetic interference. Once each freeze hole was drilled, a pipe made from 5 m lengths of fiberglass, joined by steel connecting rings, was placed inside the entire length of the borehole. These steel rings increased the potential for magnetic interference, so continual measurement was necessary to verify exact positioning and make corrections to keep drilling on track.

The task of maintaining the required drilling tolerances was also affected by the difficulty in accurately aligning standpipes in a granite formation. Standpipes were installed on the rock face at each freeze-hole entry point. These allowed the drill pipe to pass through while controlling and monitoring the considerable back pressure of water while drilling.

More than once, a standpipe was offline and required constant steering through the granite formation to ensure the borehole remained within its tolerance limits once it had entered the silt formation. Insond Gmbh supplied and operated the drilling rig, a Casagrande M9-1 Hydraulic Crawler Drill with 8 t pullback force, as shown in figure 5.

The downhole assembly consisted of a 6¾ in Tri-cone bit with TCI inserts, a magnet sub that housed the magnets for the rotating magnet system, a 4¾ in BICO motor and 4½ in drill pipe. Inside the drill pipe, just behind the motor, a Micon guidance tool was mounted to measure the orientation of the mud motor.

The position of the rotating magnet sub was measured by a Vector Magnetic guidance tool, mounted inside the sacrificial bore in the centre and moved alongside the drilling assembly, as described above. Micon designed and constructed an electrical pulley system, which was capable of moving the guidance tool up and down the pilot hole while measuring its position to within centimetre accuracy.

Freeze-hole drilling began at the end of August 2005 with two 12-hour shifts by guidance engineers from Prime Horizontal and DDS Directional Drilling Service Company, both contracted to Micon.

Operations ran around-the-clock until the final freeze hole was finished at the end of January 2006. In September 2005, while freeze-hole drilling was in progress, TBM Åsa began to drill towards the freeze-hole gallery from the southern end of the tunnel.

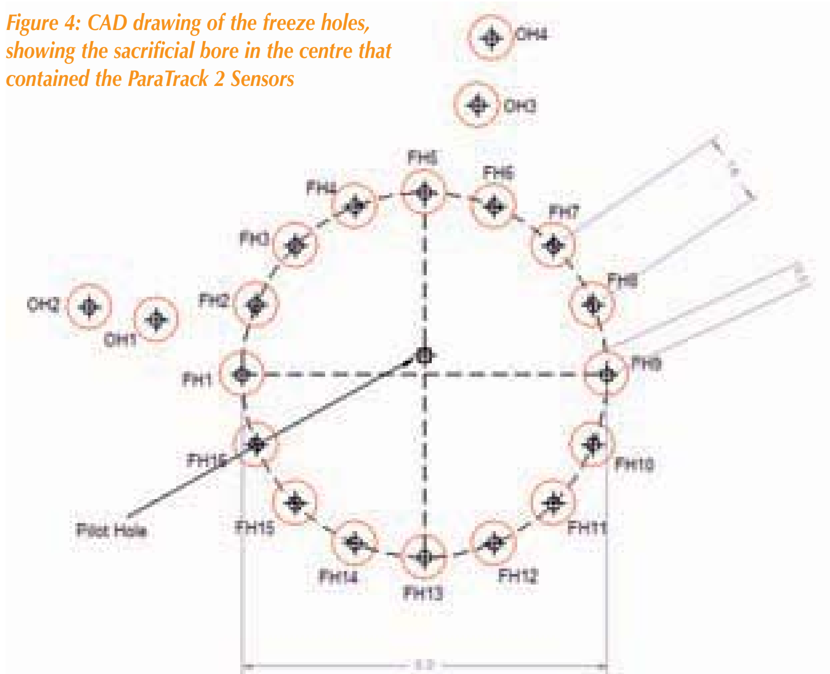
CURRENT STATUS

Freezing of the first of the two planned tunnels has now been completed, and freeze-drilling operations in the second tunnel through the same soft zone is planned to start this autumn.

Meanwhile, according to Swedish rail authority Bankverket, TBM Åsa is currently boring from the south to the northern end of the tunnel, with three kilometres remaining. Breakout at the north end is expected to take 1.5-2 years, and boring the second tunnel, again from the southern end, is expected to begin in 2010 and finish in 2012.

It is a source of great pride to Micon, Prime Horizontal and DDS to have been consulted on the Hallandsas Rail Tunnel project. Adapting the ParaTrack Rotating Magnet Guidance System used in oil-well drilling to the freeze-drilling of tunnel bores in soft formations opens up possibilities for other projects previously considered unfeasible.

Figure 4: CAD drawing of the freeze holes, showing the sacrificial bore in the centre that contained the ParaTrack 2 Sensors



Tunnel lining segments ready for assembly