Sauda sustaining superb progress

In May, a world record in drill and blast was broken at the Sauda Hydro development, western Norway. Atlas Copco's Gunnar Nord details work to date

COMPRISING 30km of tunnels and a new 500GWh underground power station, the Sauda hydro power project is probably one of the last such large-scale projects in Norway. The new US$140 million facility lies 527m above sea level, northwest of Stavanger. Construction work started in May 2005 and will be completed this year. AF Skandinavia (part of AF Gruppen) is more than two-thirds of the way through the tunnelling work.

The tunnel system comprises a number of branches that collect surface run-off water and bring it into a trunk-line feeding the power station. As the total drop is 500m, the power station's turbines can be driven by relatively low water volumes. About 175 are employed on the site, including M&E and other subcontractors.

GEOLOGY AND ROCK CONDITIONS

Granite, gneiss and meta basalts form the base rock and typify the tunnel alignment. They have generally good mechanical properties, such as high strength and low incidence of discontinuities, resulting in minimal support work. But, on the higher altitudes, there is an allochthonous nappe consisting of low metamorphic sediments such as sandstones and phyllites. The sheared zone in the bottom of the nappe is characterised by intensely jointed, altered rock material and high water influx. On top of the nappe are various gneisses that are highly jointed and altered with typically open jointing patterns.

TUNNELLING WORK AT DALVATN AND SÖNNÅ HÖY

From May 21-26, contractor AF Skandinavia smashed a world record for drill and blast: at Sauda, it achieved the greatest weekly advance on a single face – excavating 165m by drilling and blasting 33 rounds in a 38m² section, which averaged less than four hours between each blast.

Tunnelling is taking place simultaneously at four faces being excavated as single headings. Each heading has, therefore, its own set-up of construction equipment and crews. Two of the headings form one tunnel with the same cross-section, namely Dalvatn and Sönnå Höy. The feeder tunnel to this trunk line is already excavated.

View of access road

At 6.8km long, the Dalvatn tunnel-branch has a 38m² cross-section, which has been given an asymmetric shape to boost excavation speed – the offset shape allows trucks to be loaded directly at the face, thereby speeding up the whole process. Four intakes are scattered along the path of this branch, which is characterised by good rock conditions.

At the time of writing, there are less than 100m left to be excavated in the Dalvatn tunnel. The 5,300m already excavated as a single heading have been completed in 16 months, which approximates to 331m/mth.

Most of the rounds were drilled to the full depth of the 5.49m (18ft)-long drill-steel, necessitating an average of 4.8m-long rounds. This gives an advance of 2.7 rounds over 20 hours. The variation is, however, large, and in the record-breaking week, some 5.5 rounds were achieved daily. Nearly double the average advance rate was achieved at 4.6 rounds per 20-hour day.

Sönnå Höy, the other face of the double heading excavation heading towards the power station, has not advanced as fast as the Dahlvatn face. This was due to ground conditions, water inflows and, in places, a 1:7 decline, necessitating the use of pre-grouting for parts of this stretch. Single-face drifting started before the 1,500m section (likely 1,000-1,200m).

At the time of this site visit, the single-face heading had reached the 3,000m mark, so only half the overall advance rate of the Dalvatn heading had been achieved. This was due not only to the poorer ground and water-influx that required pre-grouting, but also due to areas of both uphill and downhill gradients of 1:6. The breakthrough to the tunnel leading to the penstock was only 80m away.

The two trunk-line branches described above have been given the same cross-section and used the same equipment to carry out the work. A three-boom Atlas Copco Boomer XL-4 C30 rig is drilling 85 blastholes of 48mm-diameter and four large 100mm holes.

The Atlas Copco Boomer 353 at Sönnå Hoy

Loading is achieved by a Volvo L220 with a side-dumping bucket of 3.5m³. SSE (Site Sensitised Explosive) emulsions are being used for pumping into blastholes , thus reducing the risk of accidental explosions.

Although the wheel loader is used for scaling, manual inspection is carried out from a basket mounted on the loader. Bolt-hole drilling is from the drill rig and installations are made from its service platform. AF, SRG's parent company, has subcontracted specialists for the shotcrete work, with Meyco equipment used at every face.

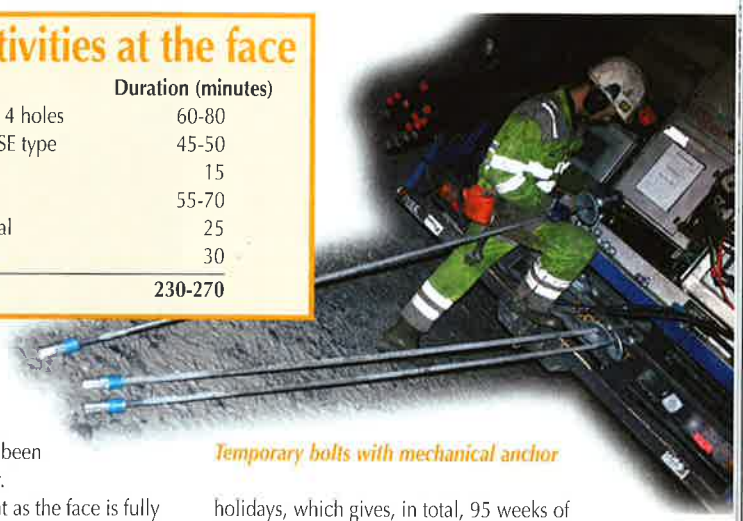
LEAN TEAMS

As is mostly the case in Norway, crew numbers have tended to be on the small side. At each of the four faces, three men are employed to drill, charge, muck-load, shotcrete and, where needed, do the grouting. In addition, three men on back-up works and two mechanics cover all four headings. This brings the total to 17 men on the shift, but the number is increased by trainees and others. Transporting the muck on 30-ton trucks is subcontracted out.

What does a round from this outstanding performance look like from a time perspective? Table 1 summarises the activities at the face, which includes the durations of each activity. When all activities are added up, the time span for a typical round is less than 4-4.5 hours. A summary of completion times for each round during the record-breaking week has been provided by the contractor.

Table 1: Activities at the face

Activity	Duration (minutes)
Drilling blastholes 85 + 4 holes	60-80
Charging Emulsion of SSE type	45-50
Ventilation	15
Mucking 200 m³ solid	55-70
Scaling Loader & manual	25
Bolting 5-6 bolts/round	30
Sum of all activities	**230-270**



Temporary bolts with mechanical anchor

A typical scenario is that as the face is fully utilised, there is no time loss, which is normally the case. This is typical as the crew had, from the start, the aim of setting a world record. Over the whole 165m, only 190 bolts were installed and no shotcrete was sprayed at the face. The advance rate per total hour comes to 1.2m and the work during the week visited was continuing round-the-clock.

When analysing the whole of the Dalvatn drift, it can be concluded that the tunnel was completed in 101 weeks. The site is closed some three weeks every year for Christmas and other holidays, which gives, in total, 95 weeks of work. Each week has 106 work-hours, including meal breaks, and on average, this gives 101 work hours per week, excluding breaks. In addition to this, there is overtime work at the face which probably brings the week hours to 106. So, the total work time at this face is only slightly more than 10,000 hours, during which 6,800m have been excavated, resulting in an average speed of 0.68m per total hour – which is 57% of the speed of the record week.

The first 1,500m meant double heading excavation, which is characterised by a slower →

advance rate. If the single drift figures typical for 5,300m are taken into account, the average speed is 0.75m per total work hour. This must be seen as a very good result, even in favourable rock conditions. The average time for a 5m round is less than 6.7 hours, giving as much as 15m/d.

But how do we explain this progress? The most important factor is the design approach. The tunnel cross-section is given an asymmetric shape that makes it possible to load the muck into dump-trucks at the face. The height and width is such that 5.48m feeds suitable for blasthole drilling can also be used for bolt-hole drilling.

The support design is split into two phases, the first at the face, which is temporary and will keep the opening stable for the time it takes the face to advance some 50-60m. And in the second phase, taking place some 30m behind the face, permanent support is added. If needed, a third supplementary support operation is performed further behind the face. This means that, in reasonably good ground conditions, minimal time is spent on support work at the face. A benefit is that the drifting is only going gently uphill.

Drilling has turned out to be very rapid. The round demands nearly 440m of 48mm blastholes and 20m of 100mm uncharged holes. With a penetration typically 3.5m (a figure from

The Atlas Copco Boomer 353

site management), the round is difficult to complete in one hour including mobilisation. The penetration rate must, over the section where the record week was achieved, be at least 4.5m/min or the number of blastholes could be reduced. But even so, to complete the round in 80 minutes is a real achievement.

As to why the rig is so reliable, it can only be said that like the Volkswagen Beetle, it just goes on and on. So how is it possible to get such efficiency out of a rig and the other equipment? Part of the explanation lies in the attitude of the Norwegian workforce, which remains at the face longer, thereby minimising the movement and time needed to return to the face after each round of blasting.

SÖNNÅ HÖY TUNNEL BRANCH

Sönnå Höy is the downstream section of the headrace tunnel. The first of some 900m were excavated as double heading, with the Dalvatn tunnel being the other heading.

This branch has the same cross-section as Dalvatn but was, in its first part, excavated downhill at a gentle gradient. Water ingress was a problem, necessitating pre-grouting, which slowed the advance rate to only 60% of that achieved on the Dalvatn side.

The second phase of the Sönnå Höy branch excavation is a single heading drifting up to the section where the Sagelva intake tunnel meets the Sönnå branch. The tunnel has the same cross-section but has an uphill slope of 1:7, with the same type of equipment used. High water ingress prevails and extensive pre-grouting is needed – two conditions that have had a major impact on the advance rate, although the individual effect of each is difficult to quantify.

If the three vacation weeks taken every year are taken into account, the 37 weeks it took to excavate 1,300m of tunnel drop to 35. This is only 0.37m advance per total work-hour, which is half the advance rate of the Dalvatn single-heading excavation. The remaining part, some 900m, has the same cross-section but is on a downhill grade of 1:6. For this stretch, the rig is the AC 353 with the Cop 1838 ME drill rig. Site

Servicing equipment

Servicing the equipment took place regularly. Weekly servicing above ground is carried out in designated tents, according to the equipment type. The exception is drill rigs, which are serviced daily underground.

Although there has been no recorded data for drill-rig availability, the general opinion is that it was very high and probably not less than 95%.

Insulated rubber tents as workshops

feedback indicates that this rig results in only 1.5m/min rate, while the Cop 3038 achieves 3.5m/min.

This affects the advance rate and so does the increased downhill gradient. Section 2,300-2,925m was excavated in six months, which corresponds to 26 weeks minus 1.5 (lost due to vacation). The advance rate is only 26m/wk: an advance rate that is only a third of the Dalvatn rate. The effect of the older rig is more than one hour per blast round and 90 minutes per grouting round.

For 130 blast rounds and 25 grout rounds, this means 180 hours in total or close to two weeks. With a Cop 3038 rig giving much faster drill-bit penetration, the advance rate would be 28m/wk. It is obvious that the steep gradient and work to prevent water ingress have had the most impact on slowing the advance rate.

WORK AT LIGNVATN AND SAGELVA INTAKE TUNNELS

These two feeder tunnels have been designed with a 27m² cross-section. Once again, the tunnel design is adapted to equipment used. But it was not possible to have the wheel loader right up to the face, so loading niches were located at 125m distances.

> "As to why the rig is so reliable, it can only be said that like the Volkswagen Beetle, it just goes on and on"

At my site visit in mid-August, the face had reached 3,622m. The excavation has been going on for 25 months and that means the average advance rate is only 36m/wk. Once again, water ingress has hampered a good advance rate. Inflows of 3,000-4,000 litres/min have been recorded. Continuous pre-grouting was applied for the whole distance from 700 to 3,000m, a stretch that included crossing the thrust zone. In general, grouting was carried out in 12 holes of 31m length, which was repeated every 25m. A pre-grouting operation of this kind normally takes a day, which means that more than 100 days have been spent purely on pre-grouting.

Rounds in this tunnel are drilled with 5.48m (18ft) feeds. To make bolt-hole drilling possible, it was necessary to have one telescopic feed. The drill-rig tunnel cross-section for the Lignvatn transfer tunnel was drawn after a sketch provided by SRG is an AC Boomer L3C with Cop 3038.

The same type of gear set-up is applied in the Sagelva transfer tunnel. The cross-section is identical, but excavation is carried out on a 1:6 uphill slope, with pre-grouting also undertaken, but to a lesser extent than in the Lingvang.

So far, 900m of the given 1,400m have been excavated. As the drifting of this tunnel began in February 2007, the average advance rate is also 36m/wk. It has been said that the top speed reached over one week is 50m. Yet it is likely that the lesser pre-grouting activity in this tunnel made it possible to achieve the same advance rate as in the Lingvang tunnel, despite the tough 1:6 uphill gradient.

Here, the telescopic feed was omitted in favour of a regular 4.87m feed for use on the bolt-hole drilling.