

NORWAY

F Nilsen and RG Haug suggest the performance, safety and quality of Norwegian tunnelling could prove a good model for other countries to follow

NORWEGIAN tunnelling is mainly based on methods and technology related to hard-rock tunnelling. With 100 years of experience, from mining and railway tunnels to hydropower plants, oil-storage caverns and modern road tunnels, Norway has devised improved techniques. Its industry is also renowned for having few accidents and a strong emphasis on environmental matters.

Decisions related to blasting, rock support, equipment and so forth are usually made at the tunnel face, grounded in the design plans and contracts. The owner and consultants are represented on site and are part of the construction team at all times. Contracts are usually unit-price contracts, with the risk placed with those best able to handle it. Future tunnelling in Norway will be more complex than today and focus on easy, cost-optimal maintenance, which will be a major concern.

Norwegian tunnelling techniques differ from those in other countries. Rock is considered to be the construction material, with drill-and-blast the main excavation method. With experience gained from more than 100 years of tunnelling, Norway has developed the technique of blasting through hard rock to an extent that rivals modern TBMs. Admittedly, a large part of its competitiveness is due to cultural traditions and a flat organisational structure.

NORWEGIAN TUNNELLING TECHNOLOGY

There are over 5,000km of transport tunnels in operation in Norway; more than 3,500km for hydropower, and around 500 caverns for storage, hydropower plants and other purposes. But, there is also growing awareness of life-cycle costs (LCC) and maintenance. All parts of the tunnelling industry are involved in and regarded as important contributors to the technology's ongoing improvement.

Although Norwegian geology is mostly hard rock, granite and gneiss, the range of rock quality is still great. Norwegian tunnels and caverns are found in all types of geology, and the experience from excavating them is gathered from a wide range of rock qualities. Tunnels are driven through everything from soft sandstone with minimal overburden to sub-sea sediments, and through clay fault zones with saltwater ingress that necessitates ground freezing to enable blasting.

Setting an example



The Hanekleiv Tunnel in Vestfold, Norway, runs through highly unstable rock conditions and was opened to traffic in October 2001

Developing this technology has helped Norway to break a few world tunnelling records, including the deepest sub-sea tunnel (Eiksund) at 287m BSL, the longest road tunnel (Laerdal) at 24.5km long, and the largest number (close to 30) of sub-sea tunnels.

Innovation and development have been driven by modern needs and challenges, such as those thrown up by the oil industry: methods have been developed for tunnel construction under the Troll Oil Field where, with an overburden of 180m of saltwater, the 'lake tap method' was used successfully three times in the mid-1990s.

Although tunnelling techniques may seem similar throughout the world, we believe there are some elements of Norwegian methods that are regarded as unique when viewed from abroad. Some of these are mentioned below.

Over the past 20 years in Norway, drill and blast has dominated as the preferred method, even though experience gathered in the mid-1980s relating to TBM tunnelling was crucial in the

“Norway has broken a few world tunnelling records, including the deepest sub-sea tunnel (Eiksund), longest road tunnel (Laerdal) and largest number of sub-sea tunnels”

global development of hard-rock models. The rock itself is considered the construction material and is supposed to bear all loads – once suitably supported – over a lifetime.

The Q-system, developed at the Norwegian Geotechnical Institute, is the world's most frequently used system of rock classification for support in hard rock. Systematic probe drilling and pre-grouting to avoid water ingress are used as planned activities in tunnelling cycles.

Used as a means of permanent support in transport tunnels, shotcrete with a quality and durability equivalent to normal concrete is applied using high-capacity shotcreting robots. High-quality, dip-galvanised and powder-coated rockbolts have been developed for tunnelling, where combined end-anchored and fully-grouted bolts, among others, are used as part of the permanent support.

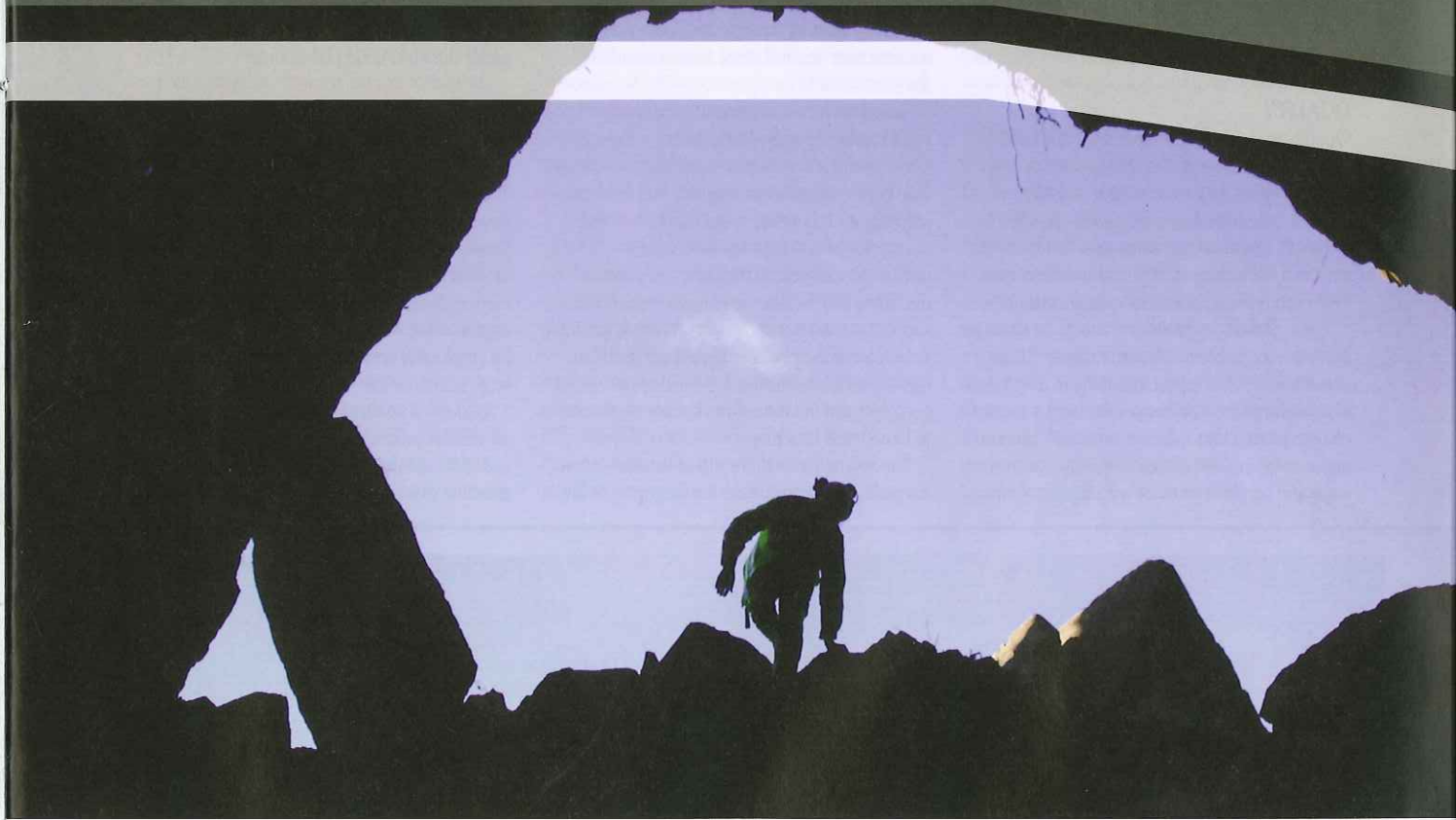
In recent decades the focus has shifted to systems that have become important elements of tunneling technology, such as those for water and frost protection, electro-technical equipment and control. Tunnel aesthetics and lighting, from a driver's point of view, still need improvement.

Contracts are usually unit price and there is a well known tradition in which risk is allocated to the party best able to handle it. The owner is usually responsible for risks relating to varying geological conditions. A contract system has evolved that is designed to handle activities that have the most impact on construction times, such as those relating to real, executed rock support rather than to planned work.

Project-related expert teams, often consisting of three people appointed by the parties to the contract, are called upon as advisors during projects, particularly for complex ones. Due to the high cost of personnel and the fact that it has only 4.5 million people, Norway has developed a curiosity and traditions for developing new

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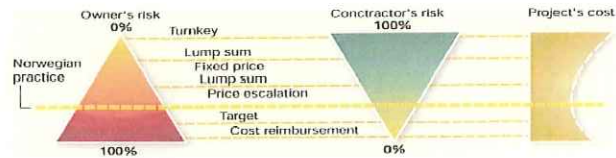
→ methods, machinery and systems to suit given purposes. A set of handbooks and regulations addressing performance, quality, standards, safety, etc, has been published by the Norwegian Public Road Administration.

Last, but not least, close co-operation at all levels of management and among the parties involved is made possible by the extensive expertise, mutual respect and knowledge available in all parts of a project. We believe these elements are the factors in Norwegian tunnelling that allow it to offer high quality, safety and excellent performance.

QUALITY

Quality amounts to the expectations related to a given structure over a certain period of time. Of Norway's 1,000 road tunnels and 800 rail tunnels there have been only a few reported instances where severe damage or failure of the structure has occurred. No fatal incidents have ever been reported due to failures in construction.

Nevertheless, rockfalls and structural damage are less acceptable in modern tunnels. Rising expectations with respect to quality in all aspects of tunnelling, especially over the long-term, will change perceptions. Maintenance will become a major concern. Cost related to quality is a growing issue and can best be dealt with during planning.



Norwegian contract practice (Kleivan, 1987; Blindheim & Grøv, 2003)

PERFORMANCE

A road or rail tunnel usually has a cross-section area of 60-80m². A normal blasting round implies three blasting rounds per day, which usually equates to a daily advance of 15m, including blasting, scaling and rock support. The rock support needed at the face is decided by the contractor in co-operation with the owner.

Based on recent experience, there is a contractually specified time for the owner to check and document rock quality at the tunnel face before shotcrete is applied. This work is usually carried out in co-operation with the contractor, and is important in order to document the rock quality, both for support decisions and long-term maintenance. Rock support carried out at the tunnel face is intended to be part of the permanent support, as far as this is possible. Thus the expertise of the geologist and the tunnel worker are combined to benefit the structure.

Tunnelling records are still of interest as long as quality is taken care of. For example, in 2003,

Leonhard Nilsen & Sønner (LNS) excavated a 5,630m-long tunnel in Spitsbergen, which had a cross-sectional area of 38.5m². Average performance was 103.3m/week, including all safety and roadwork, with a peak of 150.1m/week. This tunnel was driven partly in permafrost and under difficult Arctic conditions.

WORKING HOURS AND HEALTH

Traditionally, tunnel excavation took place in rural areas where transport and travel were time-consuming, so a tradition of shift work developed. The Norwegian Union of General Workers (NAF) and the Norwegian Association of Heavy Equipment Contractors (MEF), (the Norwegian trade union and employers' organisation, respectively), are usually requested by employees and management to agree on a work schedule that details the shifts involved.

Usually, a cycle of nine days on and 12 days off work is practised. The average working week is 33.6h, which, over three weeks, gives an effective work time of 100.8h in the tunnel.



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A few studies have been carried out to investigate the health aspects related to shift work. Such a study was carried out at Svea in Spitsbergen, where the work schedule consisted of three-week shifts working at Svea and three weeks off on the mainland. To map and document the effects of this work schedule at the University of Bergen, a co-operative agreement was signed with the Department of Public Health (occupational medicine section). Its research looked at stress, sleeping problems and psychosocial conditions.

The shift system proved very effective and deserves further study – one for the mainland, and maybe one concerning two-plus-two shifts. The final report concluded that staff showed no signs of developing health problems due to this shift pattern. Naturally, the long-term effects have not been studied. Today, testing is taking place in conjunction with a tunnel-upgrade project in order to gain more knowledge of how the human body reacts to various types of pollution. Work is continuing while traffic passes through the tunnel. These tests will be completed in a couple years.

One much used measurement in Norwegian HSE work is the lost-time injury (LTI) rate. This is defined as the number of lost-time injuries per one million employee working hours. A lost-time

injury is defined as an accident resulting in injury, where the person does not return to the next shift. Tunnel construction work has an LTI rate ranging from 0-5, while construction work is usually in the range of 5-8.

CULTURAL BACKGROUND

Tunnel workers have always been regarded highly in Norwegian construction due to their reputation of being reliable, very skilled and solution oriented. Today, education places a strong emphasis on teamwork, of which the results can be seen in tunnelling. Only a few people work at the tunnel face, but each has an important role and they share a mutual dependency. They are trained in schools and as part of a team where the most experienced workers are teamed up with trainees.

All team members are expected to be able to make the right decisions by themselves, often under stress. Co-operation with colleagues, the owner's representatives and subcontractors is also an important skill for effective work.

Traditionally, many Norwegian tunnels have been excavated in rural areas where everything needed to be set up on site, presenting difficulties in communications and distance to the site. Today, tunnels are more often situated in urban areas, where a focus on detail, progress

and the environment is important. This requires additional know-how, understanding and a will to co-operate closely with many parties.

Management is a part of on-site organisation and there is close co-operation between all levels on a project. Organisational structures are flat, both on site and in management. Responsibilities and decisions are delegated to the operational level, which discusses matters on site. Only when special technical difficulties or contractual matters arise is the next level involved. In Norway, teamwork is highly developed and a common form of co-working. Norwegian tunnel workers are very skilled and solution-oriented.

ENVIRONMENTAL ISSUES

Environmental understanding and care is perhaps the last, but certainly not the least skill for which a tunnel worker must train. Over the last two decades there have been revolutionary changes in how environmental issues are handled during construction. Environmental requirements are set early and plans are made in advance regarding water, pollution, construction waste, dust, noise, wildlife, people and neighbours, to mention a few. Such requirements are stipulated in contract documents and sometimes a bonus is awarded if the delivered product improves on the requirements. →



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NORWAY

→ EQUIPMENT, METHODS AND QUALITY

Modern tunnel equipment is an essential asset when it comes to high performance and high-quality tunnelling. Special equipment has been developed for small-scale tunnelling, for large cross-sections, for shafts, and for special tasks such as scaling, pre-grouting, handling water and frost-protection systems.

High drilling capacity combined with high operating safety is decisive in achieving high advance and high performance rates. Precise drilling is also important to achieve a smooth surface in the tunnel, which, again, is important to make rock support and shotcrete as useful as possible at an acceptable cost.

The use of computer technology and theoretical models is becoming part of the foundation of efficient Norwegian tunnelling – a development that has been driven by the equipment suppliers and contractors. Computerised drilling rigs perform precisely and efficiently, and registration of the geometry, geology and rock support is automated. There is reason to believe that we are still only at the beginning of exploiting these systems. Norwegian-manufactured drilling rigs have such systems automatically installed.

Documentation is an important part of the method and an area in which there is rapid development. Due to the increasing use of

computer technology, a variety of systems have come into common use, with more promised.

Today, drilling data is used to document cross-section, geology, as MWD (measure while drilling), for rock support, etc. The possibilities are unlimited; however, the challenge is to decide what kind of data will be needed for future use and how to present it for the long-term. This is a challenge that the owner must specify. Novapoint Tunnel is such a tool, useful for documentation, which has been developed recently for Norwegian use.

Pre-grouting as a means of preventing water leakages has been developed as an effective part of the tunnelling cycle. It is usually carried out using micro-cement and, in special cases, with chemical additives. The focus on pre-grouting is increasing for all kinds of tunnel works because the cost of taking care of water in a tunnel life-cycle perspective is a challenge.

Shotcrete, and the development of shotcrete as it is used today (as a systematic part of rock support), is a good example of Norwegian development and refined innovation over the last two decades.

Blasting developments have played a vital major role in improving health and safety in tunnel construction. The change from cartridge dynamite to emulsions has substantially reduced

nitrous gases in the tunnel. The use of emulsion explosives underground was developed by Dyno Nobel in Norway in co-operation with Norwegian contractors and clients. Dyno Nobel also developed a special charging truck that improves efficiency and accuracy, and is very important, especially for charging the contour (string loading). Nitrous gas was reduced by about 80% and CO gas by 50%.

Using emulsion explosives instead of ammonium nitrate allows loading and mucking to begin much earlier after blasting. Due to the great improvement in the working environment made by the underground use of emulsion explosives, Norwegian clients were quick to specify that only emulsion explosives should be used. Today, emulsion explosives are used for almost 100% of all underground blasting.

CONTRACTS

Some important objectives of our philosophy are safety during construction and the construction of safe tunnels within a cost-conscious framework. It then becomes important that:

- how the risk is shared is clear;
- tunnel contracts are flexible with respect to handling varying ground conditions; and
- the owner and contractor co-operate to achieve the desired results.



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Conclusions

High performance, safety and quality may be achieved due to the following:

- **Experience:** Norwegian tunnel workers are very skilled and also solution-oriented. This makes them good team players, but they are also able to make individual decisions under difficult conditions.
- **Equipment:** Norwegian tunnelling technology emphasises choosing the right equipment for a given task. A great deal of effort is also put into developing new equipment and technologies.
- **Reinforcement and rock support:** the correct choice of reinforcement method and rock support, and the use of a large degree of experience-based knowledge in addition to modern technologies, such as MWD, is vital. The use of site-sensitised emulsion (SSE) systems makes it possible to start loading shortly after each blast operation.
- **Planning and preparation:** good planning and preparation are crucial as a project progresses. A traditional project in the spirit of LNS is a slim and effective organisation.
- **Lack of conflict on site during construction:** the will to solve upcoming problems is generally present during construction. However, it is not uncommon to have contractual disputes as part of the final payment discussions.
- A strong focus on **workers' health** and **environmental issues**.

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