Norwegian Tunneling Technology
High Performance, Quality and Safe Tunneling

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Introduction

For many years, the Norwegian Tunnelling Society has endeavored to make Norwegian tunneling methods and technology better known in the international tunneling market. We believe our experience would be useful to parts of the world tunneling market.

Norwegian tunneling is based on methods and technology primarily related to hard rock tunneling. Hard rock is found in many qualities, however together with additional rock support it becomes a construction material. With 100 years of tunneling experience from mining and railway tunnels to hydropower plants, oil storage caverns and modern road tunnels, we have improved methods and techniques and can document performance rates at the upper end of the scale. The Norwegian tunneling industry also is renowned for few accidents and its great emphasis on environmental matters.

Norwegian tunneling is characterized by solid knowledge and expertise, and responsibility in all levels of the organization. Decisions related to blasting, rock support, equipment and so forth usually are made at the tunnel face, grounded in the design plans and contracts. The owner and consultants are represented onsite and are part of the construction team at all times. The contracts are usually unit-price contracts with risk placed with those best equipped to handle it.

Norway will always have many tunnels and there is a continual search for better solutions and methods. Future tunneling will be even more complex and the focus on demands for easy, cost-optimal maintenance will be a major concern.

Norwegian tunneling techniques differ from other major world tunneling techniques. The rock itself is considered the construction material, and drill-and-blast is the main excavation method. With experience from over 100 years of tunneling, we have developed the technique of blasting through hard rock to an extent that rivals modern TBMs. Admittedly, a large part of our competitiveness is due to cultural traditions and a flat organizational structure. Nonetheless, we believe our methods can be successfully used abroad. This paper addresses how and why this is the case. In it, we discuss the elements of Norwegian tunneling technology related to performance, safety and quality that are considered important.

Norwegian tunneling technology

Norwegian tunneling technology is the result of 100 years of experience related to all kinds of tunneling: from mining, hydropower tunnels and plants, storage caverns for oil and gas, tunnels
for road and rail and military purposes. More than 5000 km of tunnels for transport use, more than 3500 km of hydropower tunnels and around 500 caverns for storage, hydropower plants and other purposes are in operation. Our understanding of Norwegian tunneling technology comprises design, construction, contract philosophy and cultural aspects. A growing concern for life cost cycle (LCC) and maintenance is also part of the picture. Materials and construction methods are also involved. All parts of the tunneling industry are involved in and regarded as important contributors to the continual improvement of the technology.

Even if Norwegian geology shows a preponderance of hard rock, granite and gneiss, the range of rock quality is 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 quality. Tunnels are driven through everything from soft sandstone with minimal overburden to subsea sediments and through clay fault zones with saltwater ingress where freezing the rock material has enabled blasting. The development of this tunneling technology has made it possible for us to hold some world records in tunneling – the deepest subsea tunnel at 287 mbsl, the longest road tunnel at 24500 m, and the largest number (close to 30) of subsea tunnels – to mention some. Modern needs and challenges have driven innovation and development, and theoretically there are no limits to what the techniques can solve. The oil industry has also offered challenges and methods were developed for tunnel construction under the Troll Oil Field where, with an overburden of 180 m saltwater, the "lake tap method" was used successfully three times in the mid 1990s.

Tunneling techniques may seem to be similar throughout the world, however we believe there are some elements of Norwegian tunneling technology that are regarded as unique when seen from abroad. Some of these are mentioned below.

Drill and blast has dominated as the tunneling method of choice in Norway over the last 20 years, even though experience gathered in the mid 1980s relating to TBM tunneling was crucial in the development of hard rock TBMs internationally.

The rock itself is considered the construction material and is supposed to bear all loads once suitably supported for the purpose of the structure over a lifetime perspective.

The Q-system, developed at the Norwegian Geotechnical Institute, is the world's most frequently used system of rock classification for rock support in hard rock.

Systematic probe drilling and pre-grouting to avoid water ingress is used as a planned activity in the tunneling cycles.

Shotcrete is used as a means of permanent support in transport tunnels. The shotcrete with a quality and durability equivalent to normal concrete is applied using high capacity shotcreting robots.

High-quality, dip-galvanized and powder-coated rock bolts have been developed for tunneling, where combined end anchored and fully grouted bolts among others are used as part of permanent support.

Over recent decades, the focus has also been on a viable system for water and frost protection, electro-technical equipment and control systems as these have become important elements of tunneling technology. Tunnel aesthetics and lighting, also from a driver's point of view, still need improvement.

Contracts are usually unit price contracts and there is a well-known tradition in which risk is placed where risk is best handled. The owner is usually responsible for risk relating to varying geological conditions.
A contract system has evolved that is designed to handle activities that impact construction times the most; for example, it relates 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 the project, especially in the case of complicated projects.

Due to the high cost of personnel resources and the fact that there are only 4.5 million people in Norway, we have developed a rabid curiosity and tradition of developing new 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.

Finally yet importantly, the tradition of making decisions as close to the problem as possible, and the ability to do so, is a unique aspect in Norwegian tunneling practice. Close cooperation 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 the project.

We believe these elements are the factors in Norwegian tunneling practice that make it possible to compete in the world tunneling market with high quality, safety and excellent performance.

High quality

In many ways, this easily becomes a philosophical question. However, we regard quality to be the expectations related to a given structure over a certain period.

With Norway’s 1000 road tunnels and 800 rail tunnels, there have been only a few instances reported where severe damaged or failure of the tunnel structure has occurred. No fatal incidents have ever been reported due to failure of construction. Nevertheless, rock fall and damage to structures are less acceptable in modern tunnels than was the case when the tunnel itself represented a much greater degree of safety than high mountains and unpredictable avalanches and rockslides. Increasing demands and expectations with respect to quality in all aspects of tunneling, not least in a long-term perspective, will change perceptions of quality. Maintenance will be a major concern in future tunneling. Cost related to quality is a growing issue and can best be dealt with during the planning phase.

High performance

Usually a road or rail tunnel will have a cross section area of 60-80 m². A normal blasting round implies three blasting rounds a day, which usually means an advance of 15 m a day including, blasting, scaling and rock support. The rock support needed at the tunnel face is decided by the contractor in close cooperation 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 most often carried out in cooperation with the contractor and is important in order to document the rock quality both for rock support decisions and for long-term maintenance. The rock support carried out at the tunnel face is intended to be part of the permanent support in as far as this is possible. Thus, both the geologist's and the tunnel worker’s skills and expertise are combined to benefit the structure.

Tunneling records are still of interest as long as quality is taken care of. As an example, Leonhard Nilsen & Sonner AS (LNS) excavated a tunnel at Spitsbergen in 2003 that had a cross section area of 38.5 m² and was 5630 m long. The average performance was 103.3 m per week including
all safety and roadwork, with a peak of 150.1 m per 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. Thus, a tradition in tunneling 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’ organization, respectively] are usually requested by employees and management to agree on a work schedule entailing shifts. Usually a cycle of nine days at work and 12 days off work is practiced. The average workweek is 33.6 hours, which when distributed over three weeks implies an effective workweek of 101.8 hours in the tunnel.

A few studies have been carried out to investigate the health aspects related to working in shifts. Such a study was carried out at Svea in Spitsbergen where the work schedule consisted of shifts of three weeks work at Svea and three weeks off on the mainland. To map and document the effects of this work schedule, a cooperative agreement was signed with the Department of Public Health and Primary Health Care, Section for Occupational Medicine, at the University of Bergen. Research was carried out in the areas of stress, sleeping problems and psychosocial conditions.

The shift system proved very effective. It deserves further studies – one on the mainland, and then perhaps one of a two plus two shift. The final report concluded that the employees showed no signs of developing health problems due to this shift schedule. Naturally, the long-term effects have not been studied.

Today, ongoing testing is taking place in conjunction with a tunnel upgrade project. Testing is being carried out to obtain more knowledge of how the human body reacts to various types of pollution. The tunnel work continues 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 injuries (LTI) rate. Lost-time injury frequency rate (LTI-rate) is defined as Number of lost-time injuries per 1.000.000 employee hours. Lost-time injury is defined as an accident resulting in injury and where the injured person does not return to the next shift.

The LTI rate is the number of lost time injuries per million working hours. Tunnel construction work has an LTI rate ranging from 0-5, while construction work in general is usually in the range of 5-8.

**Cultural background**

In Norwegian construction work, tunnel workers always have held a special role. They have a reputation of being reliable, very skilled and solution-oriented. Today, education places a strong emphasis on teamwork and the results of this can be seen in tunneling. There are only a few people working 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 great stress. Cooperation with their own colleagues, the owner's representatives and subcontractors is also an important skill that is needed to work effectively.
Traditionally, many Norwegian tunnels were excavated in rural areas where everything needed to be set up on site, and the distance to the site and communications presented difficulties. Today, tunnels are more often situated in the middle of cities and urban areas where a focus on details, progress and the surroundings is important. This requires additional knowledge and the understanding and will to cooperate closely with many involved parties.

All these skills have been developed and passed on to the current generation of tunnel workers, who still maintain their special role in the field of construction. They always have been and still are well paid and better off economically than average construction workers.

Management is a part of the onsite organization, and there is close cooperation among all levels in a tunnel project. Organizational structures are flat both at project sites and in management. Responsibilities and decisions are delegated to the operational level, which discusses matters onsite. Only when special technical difficulties or contractual matters arise is the next level involved. In Norway, teamwork is highly developed and a common way of cooperating. Norwegian tunnel workers are very skilled and solution oriented. They are able and willing to make decisions by themselves.

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. Many parties are involved. Environmental requirements are set early and plans are made in advance regarding water, pollution, construction waste materials, dust, noise, wildlife, people and neighbors to mention a few concerns. Such requirements are stipulated in contract documents and sometimes, a bonus is awarded if the product delivered improves on the requirements.

Equipment, methods and quality

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

High drilling capacity combined with high operating safety is decisive in achieving high advance rates 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 of theoretical models is becoming part of the foundation of efficient Norwegian tunneling – a development that has been driven by the equipment suppliers and the contractors. Computerized 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 ongoing rapid development. Due to the increasing use of computer technology, a variety of systems has come into common use, and more are 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 the owner must specify. Novapoint Tunnel is such a tool, useful for documentation, that has recently been developed for Norwegian use.

Pre-grouting as a means of preventing water leakages has been developed as an effective part of the tunneling cycle. Pre-grouting is usually done 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 an important major role in improving HSE in tunnel construction. The change from patronized dynamite to emulsions has substantially reduced nitrous gases in tunnel. The use of emulsion explosives underground was developed by Dyno Nobel in Norway in cooperation with Norwegian contractors and clients. Dyno Nobel also developed a special charging truck that has made the charging very efficient and accurate, and was very important especially for charging of the contour (string loading). Nitrous gas was reduced by approximately 80% and CO gas by 50%. Using emulsion explosives instead of ammonium nitrate, loading and mucking could begin much earlier after blasting. Because of the great improvement in the working environment the underground use of emulsion explosives made, Norwegian clients were quick to specify that only emulsion explosives be used. Today, emulsion explosives are used for almost 100% of all blasting done underground.

Contracts

This paper will not treat contractual matters in depth; however, some important objectives of our philosophy are safety during construction and safe tunnels within a cost-conscious framework. It then becomes important that

- how the risk is shared is clear
- our tunnel contracts are flexible with respect to handling varying ground conditions
- the owner and the contractor cooperate to achieve the results we want.
Norwegian practice sharing risk

Figure 1. Norwegian contract practice (Kleivan, 1987; Blindheim & Grøv, 2003)

Conclusions

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

- Norwegian tunnel workers are very skilled and solution oriented. Tunnel workers have extensive experience to contribute to teamwork and are able and willing to make the right decisions by themselves under difficult conditions.
- The right choice of equipment. Norwegian tunneling technology emphasizes choosing the right equipment for a given task. A great deal of effort is also put into developing new equipment and technologies.
- The correct choice of reinforcement methods and rock support, and the use of a large degree of experience-based knowledge in addition to modern technologies such as MWD. Use of the site sensitized emulsion (SSE) system makes it possible to start loading shortly after each blast operation.
- Good planning and good preparations as the project progresses. A traditional project in the spirit of LNS is a slim and effective organization.
- A lack of conflict onsite while the projects are under 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 tunnel workers’ health and environmental issues.

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