Comments to the paper

Norwegian tunnel builders are the world's best – a myth?

by Arild Palmström, MSc, PhD., Rockmass AS

During the NFF[1] Fall Conference on 27 November 2014, Dr. Palmström presented points of view on the Norwegian tunnellers. Some of us assuming that the level of competence is high (even extremely high) whereas others, and the author, have a more factual view. His presentation underscores some facts rocking the bases for exaggerated self-esteem. In the following you will find a selection from his paper.

***Arild Palmström** is well known in the Norwegian geo-engineering sector, he is author of numerous papers, author or co-author of books on rock mechanics, and has wide experience from projects worldwide. In his thesis (Doctor Scientiarum Oslo University 1995), an important part concerns methods for collecting and using geological parameters with focus on block size, rock material and the quality description of the rockmass defined in the index RMi.*

Summary

Some Norwegians within the underground construction environment boast of our tunnellers (not limited to the crew at tunnel face), claiming that these obtain weekly advance higher than competitors abroad. Frequently one will hear that the Underground Olympic Hall in Gjövik (some 100 km north of Oslo) is the largest underground opening for public use, the Laerdal Tunnel is the longest road tunnel, or that one will find the deepest subsea road tunnel on the west coast of the country, and repeatedly that the largest number of underground power house complexes will be found in our country. The Greek word hybris (*arrogance*) fits well, maybe mixed with ignorance, one may say.

Introduction

Norwegian tunnellers, one must admit, developed some good processes within hydropower development. Unlined shafts and tunnels exposed to high head water pressure, lake tap methods exploiting lakes as natural water reservoirs. The lake tap method is also successfully integrated in the oil and gas industry for shore approach of pipelines from offshore fields.

The various new designs and implementations served developers well, cost efficient as well as safe. The method with air cushion chamber for deep seated power generators is another example.

During the period from the early sixties to the end of the seventies, a peak period for hydropower development, our tunnellers may have been the number ones. Their skills however, used to be a local secret. One must not forget that there were few formal restrictions, the contracts shorter, owners relied to greater extent on initiative and decisions at site by competent staff and well-trained crews.

The tunnelling in Norway today is marginal different from the tunnelling in other advanced tunnelling markets. Most technical elements used are common practice worldwide. Extensive exploratory drilling from face combined with grouting as integral part of a tunnel contract may be better developed in Norway than in most tunnelling markets abroad. For the subsea tunnelling these activities are crucial, and in fact saved several tunnels from collapse.

The non-technical side of projects, that includes the relationship and behaviour between the parties (owners-designers-contractors-suppliers), the contract format, the handling of risk elements, the use of manpower and more, differs from one country to another. What would be typical for Norway is the risk allocation/distribution.

Maybe, he adds, the Norwegians were among the best in the world during the 1960s and 1970s, but this fame and impressive tunnelling activities were hardly known outside the country.

[1] Some information on the NFF Fall Conference is presented at the end of this paper
NFF = Norwegian Tunnelling Association

The Norwegian tunnelling method (or better called Norwegian way of tunnelling) is not very special as most of the elements included are frequently used in other countries. The probe drilling combined with pre-grouting ahead of the work face might be called a Norwegian speciality. It has saved several tunnels from collapse and/or high water ingress when unforeseen geological conditions have been encountered.

How to improve the tunnelling activities?

Project owners, contractors and consultants must find ways for better cooperation if Norwegian tunnel builders shall continue as part of the prime league. Contracts for planning and tunnel construction must be improved, not least how the successful winner of a contract should be selected. The practice today with a new contract in every phase of the project, reduces the incentive for producing a good job. This is also the case for competition on price for planning. Fixed price for tunnel contracts where the construction material is influenced by geological uncertainties is not a good solution.

Whether Norwegian tunnel builders are the world's best? The author is of the opinion that at least the "Norwegian tunnelling crew is the world's best – in Norway".

Worldwide best on what?

When talking of best or even worldwide best, is it reasonable to compare skills and achievements of others. Where and how are our own achievements the best? For example:

- Are Norwegian tunnels the longest?
- Are Norwegian underground openings the largest?
- Have Norwegian tunnel crews achieved larger weekly progress than other crews?
- Is the Norwegian tunnel quality outstanding or even best?

Other aspects to be discussed if worldwide best is the actual topics:

- Best solution/"design" of underground facilities.
- Best experience, best methods of construction/best way of handling the work.

Table 1: Longest tunnels in the world (ref. http://www.lotsberg.net/)

Name	**Length** (m)	**Country**	**Opened**	**Type of tunnel**
Seikan	53,850	Japan	1988	Railway
Channel tunnel	50,450	England-France	1994	Railway
Lærdal	24,510	Norway	2000	Road
Shin Kanmon	18,716	Japan	1975	Railway
Zhongnanshan	18,040	China	2007	Road
St. Gotthard	16,942	Switzerland	1980	Road
Arlberg	15,516	Austria	1978	Road
Lötschberg	14,612	Switzerland	1913	Rail
Micangshan	13,800	China	?	Road
Marmara	13,600	Tyrkia	2010	Rail
New Erlangshan	13,433	China	?	Road
Hsuehshan	12,942	Taiwan	2006	Road
Frejus	12,898	France-Italia	1980	Road
Maijishan	12,878	China	2009	Road
Mont Blanc	12,288	France-Italia	1965	Road
Gudvangen	11,611	Norway	1991	Road
Baojiashan	11,428	China	2009	Road
Folgefonn	11,185	Norway	2001	Road

The numbers speak for themselves. Within the next years the longest tunnels will be as per table 2.

Due to topography Norway is a country where tunnels are needed, also in the coastal areas. Many subsea tunnels are constructed, more will come. One of these is the 25 km long Rogfast subsea Road tunnel northbound from Stavanger.

Table 2. World’s longest tunnels from 2017 (ref: http://www.lotsberg.net/)

Name	Length (m)	Country	Opened /Estim. opened	Type
Gotthard base	57,072	Switzerland	2017	Rail
Brenner basis	55,392	Austria	?	Rail
Seikan	53,850	Japan	1988	Rail
Channel tunnel	50,450	France -UK	1994	Rail
Lötschberg alptransit	34,600	Switzerland	2007	Rail
Laerdal	24,510	Norway	2000	Road

Table 3: The longest subsea tunnels (from web-side http://www.lotsberg.net/)

Name	Length(m)	Country	Opened	Type
Seikan	53,850	Japan	1988	Rail
Channel Tunnel	50,450	UK-France	1994	Rail
Shin Kanmon	18,716	Japan	1975	Rail
Marmara	13,600	Turkya	2010	Rail
Tokyo Aqua	9,583	Japan	1997	Road
Chanxing	8,950	China	2009	Road
Storebaelt	8,024	Denmark	1997	Rail
Bömlafjord	7,931	Norway	2000	Road
Eiksund	7,797	Norway	2008	Road
Oslofjord	7,390	Norway	2000	Road
Severn	7,008	UK-France	1886	Rail
Nordkapp	6,875	Norway	1999	Road
Westerschelde	6,650	The Netherlands	2003	Road
Quing - Huang	6,170	China	2011	Road
Nordöyatunnilin	6,100	Faroe Isl.	2006	Road
Xiamen Xiangan	5,960	China	2010	Road

What about large underground openings? The Gjövik Olympic Mountain Hall may be a world number one as span is concerned. Very few would know.

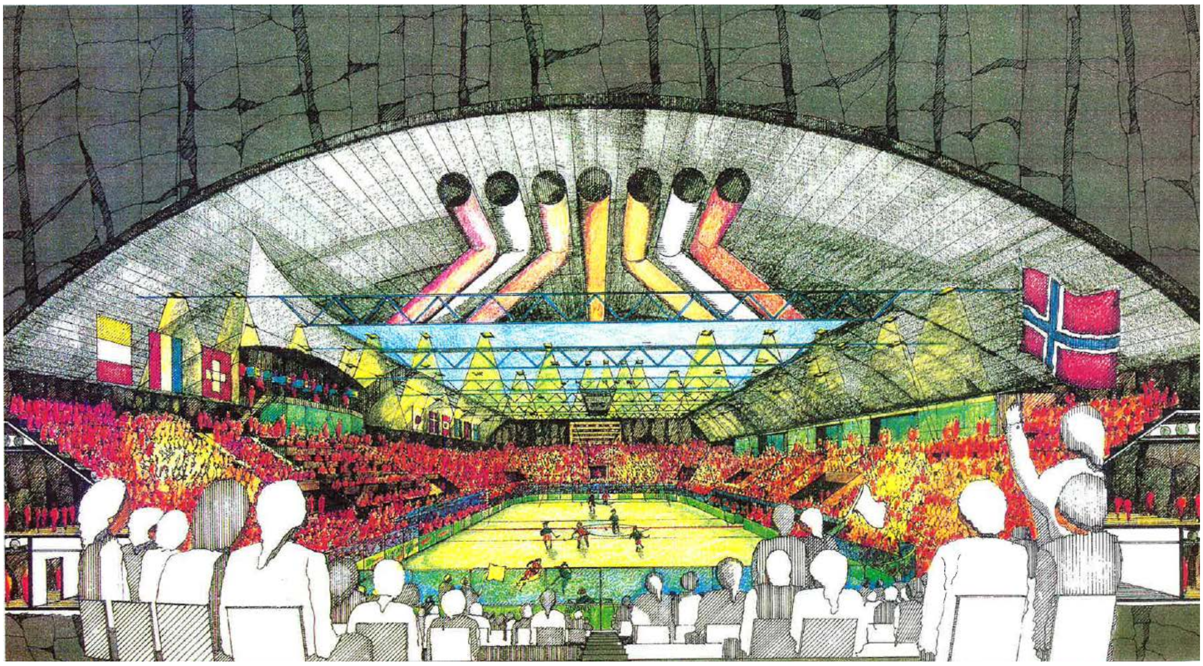

Figure 1: Gjövik Olympic Mountain Hall with a span of 62 metres may be the largest of its kind.

Advance during tunnel excavation by the drill and blast method

From an advance of 1.5 to 7 metres/month while using 'loosening rock by heating' for excavating galleries some four to five hundred years ago, the advance had reached 60 metres/week during the period 1940-1960. Using modern machinery and up-to-date methods, machinery and charging systems the advance has increased considerably. The January 2008 issue of World Tunnelling had a notice concerning the Sauda Hydropower Project (south-western part of Norway). The contractor AF Group had achieved 165 metres/week progress in the 38 m^2 headrace tunnel. In 2011, the contractor Veidekke managed 176 m/week progress in a 17 m^2 tunnel for the Kjösnesfjorden Hydropower project.

In comparison with TBM, in 1992 at Meraker Hydropower in the middle part of Norway, a 3.5 m diameter Robbins bored 427 m during the best week. (good for the contractor)

Tunnel quality

What about excavated tunnel quality (important for the developer/owner)? Smooth contour indicates quality work. Figure 4 is a picture from Tokke Hydropower, southwest of Oslo some fifty years ago. It is difficult to find the same quality contour today at home. Figure 5 is a picture from China four years ago demonstrating good tunnel roof contour.

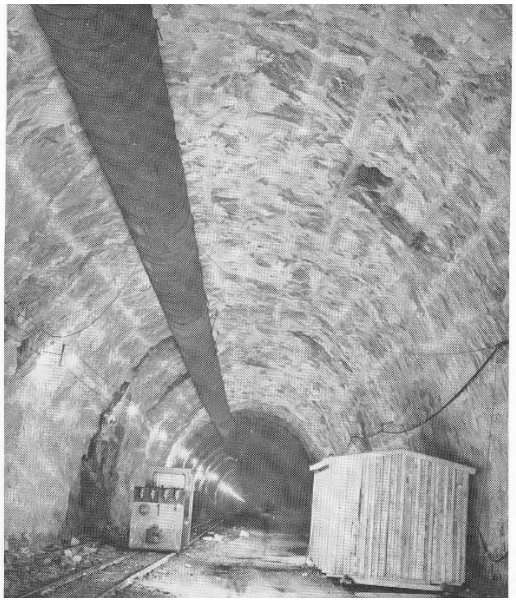

Figure 4: Tunnel at Tokke in the 1960s

Figure 5: Tunnel in China 2010

The lake tap method

The Lake Tap Method referred to as a Norwegian Speciality was introduced as a cost-efficient way of exploiting numerous lakes as long term water storage of water for the hydropower industry. The tap increased the live storage of the lake, frequently in combination with damming.

Figure 7 explains the principles of the method.

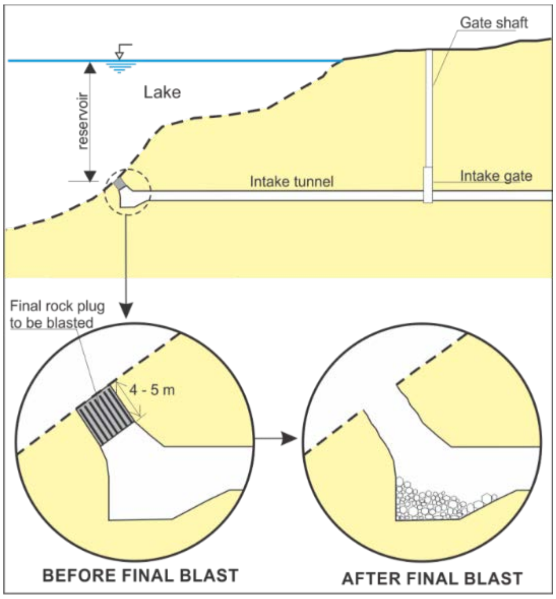

Figure 7: Lake tap principle

Subsea tunnels in Norway

Since the first road tunnel connecting Vardö city with the mainland was built in 1979 – 82, close to fifty subsea road tunnel projects have been constructed.

All along the country one will find subsea tunnels crossing fiords or connecting islands to the road system. It may be called a speciality. Subsea tunnelling requires exploratory drilling from face during the construction period. If necessary execution of quality pre-grouting to seal off water inflow and to improve/strengthen the rock mass. The longest subsea tunnel today (end of 2014) is close to 9 km long. Eiksund tunnel, 7.9 km long goes down to 287 m. below sea level (bsl.).

Table 5: A selection of subsea tunnels in Norway

Name	**Length** (m)	**Depth** m bsl.	**Opened**	**Route**
Karmöy tunnel	8,900	139	2013	County road no. 47
Bömlafjord tunnel	7,888	263	2000	European road no. 39
Eiksund tunnel	7,765	287	2008	County road no. 653
Oslofjord tunnel	7,306	134	2000	Classified road no. 23
Nordkapp tunnel	6,875	212	1999	European road no. 69
Byfjord tunnel	5,875	223	1992	European road no. 39
Atlanterhav tunnel	5,779	250	2009	County road no. 64
Finnøy tunnel	5,685	200	2009	County road no. 519
Hitra tunnel	5,645	264	1994	County road no. 714
Fröya tunnel	5,305	164	2000	County road no. 714
Freifjord tunnel	5,086	130	1992	Classified road no. 70
Mastrafjord tunnel	4,424	133	1992	European road no. 39
Valderøy tunnel	4,222	137	1987	Classified road no. 658

Most of the above tunnels are connected to special circumstances, such as local initiative, several constructed in spite of bad economy, some as substitute for expensive ferry connections.

The first road tunnel (Vardö) was in fact planned to be a bridge. Detailed drawings had been prepared, Parliament had okayed the project and allocated the necessary funding. While undertaking the last preparations prior to construction a sudden reconsideration of the climatic and geotechnical challenges caused the dramatic change to a tunnel project. Also, to be mentioned is a tunnel under the Frierfiord some 150 km southwest of Oslo. The tunnel is 3.6 km long, depth 256 m bsl. built for gas pipes, opened 1976 which means 8 years ahead of the first road tunnel.

Underground construction contracts

Most tunnel contracts are based on tendering. The tender documents are prepared by the owner and his advisers, based on national standards, a unit price system, optional items to allow for flexibility as needed, estimated quantities and a system to monitor additional or reduced compensation linked to the construction schedule (equivalent construction time). Preplanning site investigations are undertaken by the owner, the reports are annexed to the tender documents for the tenderer to analyse and draw his conclusions. For some projects a baseline conclusion prepared by the owner is available.

The Norwegian Method of Tunnelling (NMT)

The term "Norwegian Method of Tunnelling" or "NMT" was first time presented in the beginning of the nineties. This may have happened as a consequence of the successful (Neue Österreichische Tunnelbauweise NÖT, or NATM in English New Austrian Tunnelling Meth)

NMT includes a combination of the following elements/principles (Ref. Gröv 2012):

- Exploratory Probe Drilling – from face during excavation
- Handling of Water Problems/Ingress by means of pre-grouting
- The Rockmass is a good construction material, its structural qualities are exploited.
- Rock support by means of bolts and sprayed concrete, heavy support as necessary depending on encountered geology.
- Drained structure, no need to apply static water pressure in the structural analyses.
- Water- and frost-support is installed independently of stability support.

The probe drilling and pre-grouting may be called a Norwegian speciality, the other items listed are also commonly used by tunnellers in other markets.

The development of drilling ahead of tunnel face for rock quality probing.

An important element of Norwegian subsea tunnelling is a system for rock quality sounding ahead of face as an integral part of the excavation. While drilling the next round, some inspection holes of 20 to 25 m length are established. Observation methods will either confirm expected rock quality or reveal indications on unexpected situations, potential problems like water bearing layers or other situations requiring special attention. The system has saved several projects, i.e. the Oslofjord tunnel, Bjoroy or the Atlantic Ocean Tunnel.

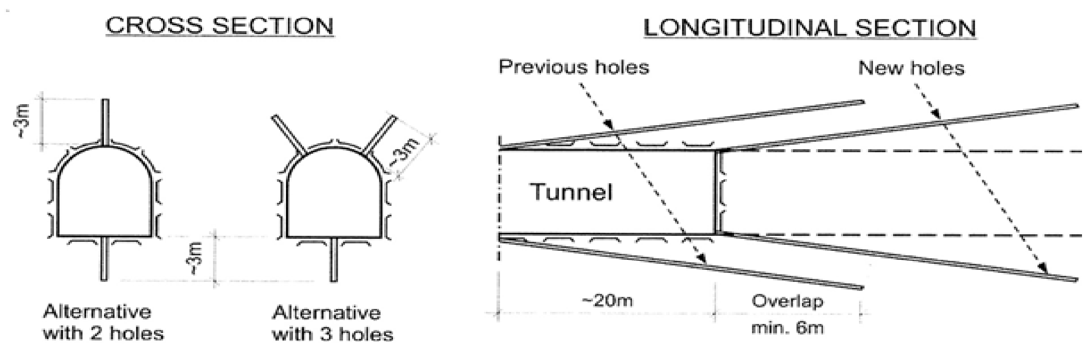

Figure 8: Prof. Bjørn Nilsen (in NFF Publ. 23) indicates probe drilling commonly used in Norwegian tunnelling today.

Grout injection

One may say that long holes and high pressure is a typical Norwegian approach to grouting. It tends to be a standard procedure. A general suggestion would be to enhance increased flexibility. The grouting and the injection pressure must always adapt to the overburden and the actual rockmass situation in general.

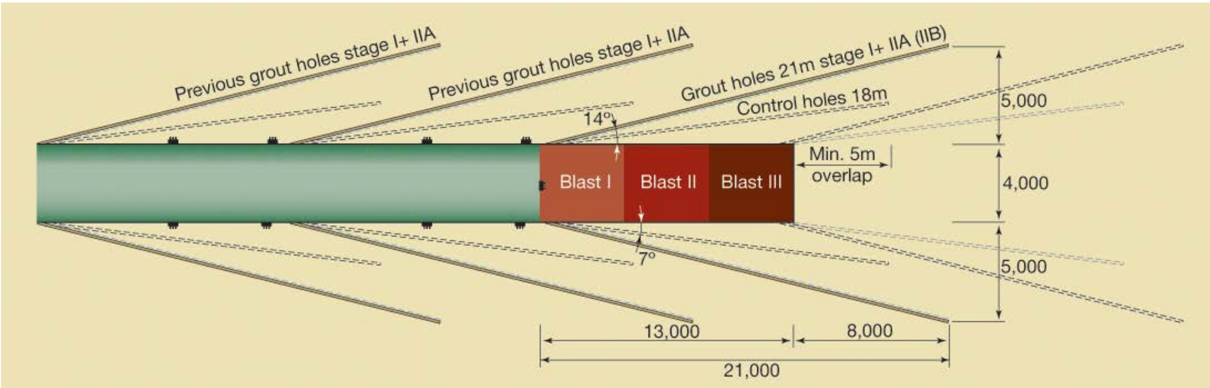

Figure 9: General tunnel pre-grouting system. Courtesy Ola Voldmo.

Vinstra Hydropower project. Rock fall blocking the headrace tunnel

Upper and Lower Vinstra Hydropower stations utilizes heads of 330 and 448 m respectively. The two power stations some 70 km north of Lillehammer started production 1959 and 1958. In the eighties the lower station was reconstructed. The new 35 m^2 unlined headrace tunnel opened for operation in 1989. Two years later serious rock slide and tunnel cave in blocked the tunnel. Inspections revealed blockage 2.5 km upstream from the powerhouse.

Rock debris were observed all along the 2.5 km with rock quantity estimated to 15.000 m^3

The removing of the collapse debris, excavation of a 180 metres long by-pass tunnel (Figure 10) and concrete plugs took only 18 weeks, thanks to effective planning and an efficient contractor.

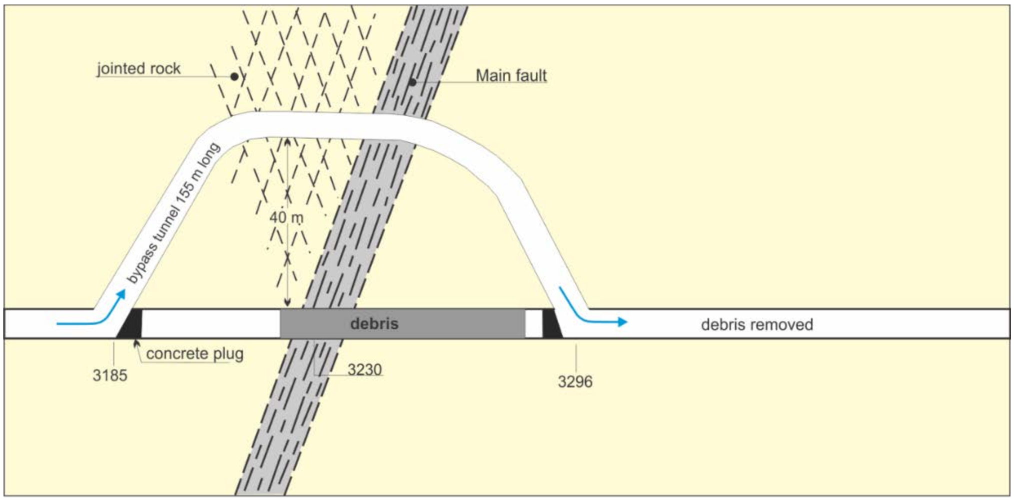

Figure 10: A 155 m long bypass was established. Removal of debris took place. Necessary management discussions, decisions, re-planning, and construction work caused by the incident took 4 months.

The Oslofjord tunnel

The 30 km long new east-west road connection some 30 km south of Oslo includes 6 tunnels. The Oslofjordfjord tunnel, a 7.2 km long subsea tunnel crossing the fiord is an important part of the project. The excavation started in 1997 and the project opened in 2000.

On the west side (Hurum) of the fiord crossing a large fault zone was detected during the pre-planning investigations, using refraction seismic technique. During subsequent preconstruction, investigations core drilling took place with one hole from the western shoreline and a second from a nearby islet (Figure 11). Both holes were drilled to a level slightly below the planned tunnel, further analyses revealed information on fault dimension and rock quality.

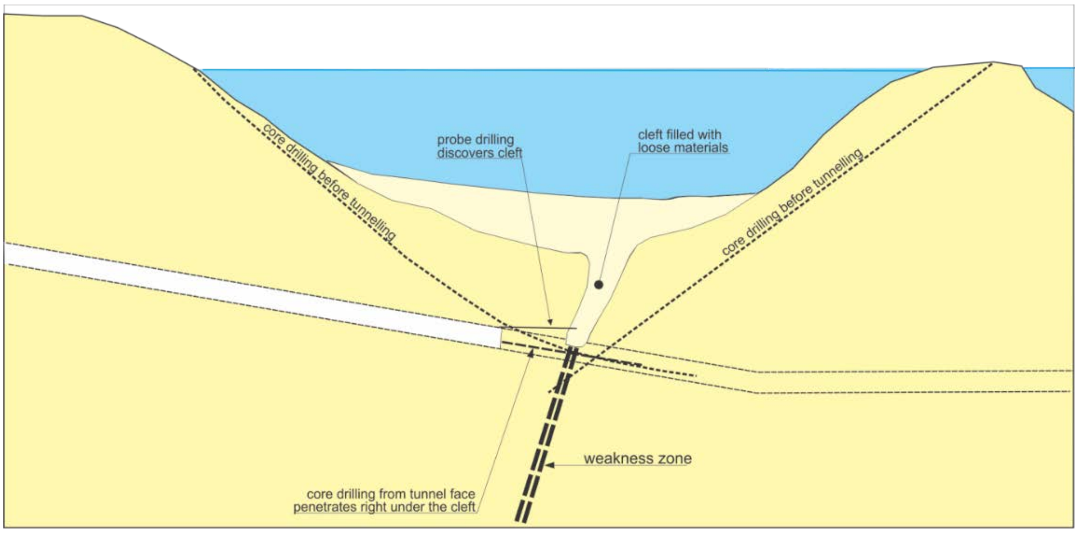

Figure 11: The tunnel had been excavated downwards to 100 m below sea level when the probe drillings from the tunnel working face discovered that the weakness zone had been excavated to a deep cleft

While excavating the tunnel late -97 the preface probe-drilling discovered serious problems ahead. The 15 metres wide fault had been eroded almost down to the centreline of the tunnel. Further rounds would reach sand, gravel, boulders and water leakage far beyond handling capacity. Grouting proved impossible with freezing being the only option.

In hindsight: Investigations were misinterpreted. Reason: No check of rockmass above the tunnel. Due to the preface probe-drilling a catastrophe was avoided. Also in hindsight: Project management and crew handled the situation extremely well. Impressing how the large fault filled with eroded material and salt water 100-metres below sea level was excavated. A time-consuming freezing process though, as will be seen from Table 6.

Table 6: Approximate time-consumption for investigations, freezing operation and tunnel excavation

Investigations, excavation of diversion, grouting of same:	3.0 months
Establish holes for freezing equipment	10.0 months
Rig for the freezing process:	1.5 months
Freezing:	3.5 months
Excavation of frozen tunnel section:	2 months
SUM	20 months

Atlanterhavstunnelen (The Atlantic Ocean Tunnel)

The tunnel is part of the southbound road from Aalesund city on the Norwegian west coast. While excavating this subsea tunnel in 2007, when reaching level 230 m bsl. a cave in occurred.

A fault zone had been registered during the preconstruction investigations. Misinterpretations during the grouting process lead to serious water in leakage. The leakage reached 500 litres/minute and water pressure 23 bar. The rockfall caused an opening of some 10 metres above the tunnel roof (Figure 12).

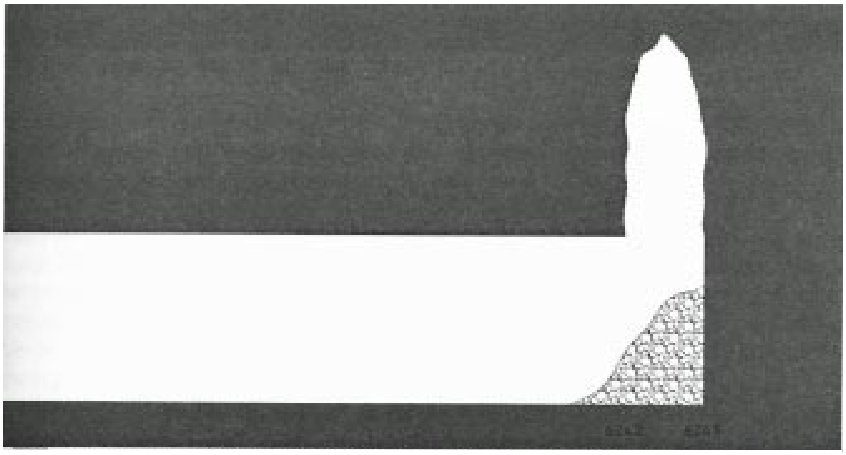

Figure 12: Rock debris at tunnel face while rock fall expanded the opening, reaching the height of more than 10 m. The handling of the dangerous situation caused anxiety due to modest rock cover.

During a hectic 10 months period extensive support work took place before the 40 metres zone had been established as a safe tunnel section. The emergency construction work established a concrete plug followed by time-consuming support work including a grouting operation requiring close to 1000 tons grout.

The Bjoröy tunnel

This concerns another subsea road tunnel, this time in the Bergen city area. The contract established by the owner in discussions with a large contractor had the “all inclusive – lump sum format”.

During the excavation, the probe drilling ahead of the tunnel face detected a fault zone later called “the sand zone”. One had never before (disregarding a minor occurrence at Andöya 1000 km further north) observed similar sedimentary, loose rock in Norway. The later appointed expert panel described the fault system to be an occurrence of a Jurassic formation with competent sandstone, sedimentary breccias and unconsolidated sand with both discontinuous lenses and continuous layers of sand and silt. Coal fragments occurred in several soil layers.

The expert panel (owner, contractor and advisor) analysed 3 optional methods for excavation trough the fault zone: (i) Freezing; (ii) Conventional grouting; (iii) Jet-grouting. Conventional grouting was applied.:

- The fault zone was detected in September 1994 and work was stopped
- January 1995 work restarted in line with decided method.
- The actual work took 23 weeks using 242 t. cement, 16 t. acryl and 280 m^3 sprayed concrete.

Once more, the probe drilling from tunnel face had revealed unexpected geology ahead. Well experienced owner and contractor approached the problems efficiently, analysed professionally and took the necessary decisions and concluded the work successfully

(The incident caused unexpected expenses. The all-inclusive lump sum contract included no provisions for handling the actual situation. The contractor suffered and asked for compensation. The contract partners were unable to conclude an agreement and the matter was solved through litigation.)

About the NFF Fall Conference

Smooth tunnelling in line with the planned progress and economy is not always the case. Sometimes one will meet unexpected difficulties, for some rather few projects the problems turn out to be serious. Such incidents, mistakes or lessons learned, are frequently presented by papers for domestic conferences, workshops or similar events.

For Norwegian tunnellers the annual *NFF Fall Conference* has been the most important arena for exchange of information on tunnelling matters during the recent fifty years.

During the first seven years, most presentations concerned ongoing projects, new techniques, new machinery and production capacities. The increasing interest in rock mechanics led to cooperation with NBG (Norwegian Group of Rock Mechanics and member of ISRM). From 1970 onwards, the conference is a joint undertaking, five years later also NGF (Norwegian Geotechnical Society) joined in. The oil and gas sector, increasingly important for the country, introduced presentations of new challenges onshore.

A review of the Fall Conference proceedings from1963 through 2014 the number of papers by topics shows:

- Project summaries, techniques, equipment, blasting methods 907 papers
- Rock mechanics, engineering geology 394 papers
- Rock mechanics/Geotechnique 218 papers
- Geotechnique 276 papers

A fair guess would be that the total 1795 papers presented, represent some 20.000 pages.