Tunnelling problems and how these problems were solved

During the NFF Fall Conference on 27 November 2014, Dr. Palmström presented points of view on tunnelling in Norway. In his presentation, he on one-hand side underscores some facts rocking the bases for exaggerated self-esteem, on the other hand side also praises the ability of the contractors to solve serious tunnelling problems. In the following, you will find a second selection from his paper.

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 learne, 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 tunneling 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.

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, Bjaroy or the Atlantic Ocean Tunnel.

Figure above (Prof. Bjørn Nilsen, NFF Publ. 23) indicates probe drilling commonly used in Norwegian tunneling 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.

Vinstra Hydropower. 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 m long by-pass tunnel and concrete plugs took only 18 weeks, thanks to effective planning and an efficient contractor.
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 fjord 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 fjord crossing a large faultzone was detected during the pre-planning investigations using refractionseismic technique. During subsequent preconstruction, investigations core drilling took place with one hole from the western shoreline and a second from a nearby islet. Both holes were drilled to a level slightly below the planned tunnel, further analyses revealed information on fault dimension and rock quality.

While excavating the tunnel late -97 the preface probedrilling discovered serious problems ahead. The 15 m wide fault was 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.

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

In hindsight: Investigations were mis-interpretet. 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 below.

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

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigations, excavation of diversion, grouting of same:</td>
<td>3.0 months</td>
</tr>
<tr>
<td>Establish holes for freezing equipment</td>
<td>10.0 months</td>
</tr>
<tr>
<td>Rig for the freezing process:</td>
<td>1.5 months</td>
</tr>
<tr>
<td>Freezing</td>
<td>3.5 months</td>
</tr>
<tr>
<td>Excavation of frozen tunnel section:</td>
<td>2 months</td>
</tr>
</tbody>
</table>
**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 b.s.l. 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: Rock debris at tunnel face while rock fall expanded the opening, reaching the height of more than 10 metres. The handling of the dangerous situation caused anxiety due to modest rock cover. (Karlson, 2008).]

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 timeconsuming support work including a grouting operation requiring close to 1000 tons grout.

**The Bjørøytunnel.**

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 sandzone”. One had never before (disregarding a minor occurrence at Andøya 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 occured in several soil layers.

The expert panel (owner, contractor and advisor) analysed 3 optional methods for excavation through 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 m³ 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.)