UNDERGROUND OPENINGS
– OPERATIONS, MAINTENANCE AND REPAIR

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UNDERGROUND OPENINGS
OPERATION, MAINTENANCE AND REPAIR

The present publication, No. 17 in the English language series from the Norwegian Tunnelling Society NFF, has – as always – the intention of sharing with our colleagues and friends internationally the latest news and experience gained in the use of the underground; this time with focus on the maintenance and safety of underground openings during operation.

Based on experience and knowledge linked to the Norwegian tunnelling industry, focus is set on rules and regulations; durability and maintenance costs in a lifetime perspective as seen from the owners; safety and reliability as seen from the public; methods, techniques and materials as seen from scientists, advisers, suppliers and contractors.

The publications of NFF are prepared by members under guidance of a purpose appointed editorial committee, this time of two members only. However, and right in the middle of the work one of the two, Espen Moe, passed away. As substitute Gunnar Gjæringen stepped in.

We, Knut and Gunnar have shared the remaining editorial work load. In memory and tribute to a dear colleague that did not make it to the finishing line, his name is still with us.

On behalf of NFF we express our sincere thanks to the authors and contributors of this publication. Without their efforts the distribution of Norwegian tunnelling experience would not have been possible.

Oslo, August 2008

Norwegian Tunnelling Society
International Committee

The Editorial Committee

Knut Fossum   Gunnar Gjæringen   Espen Moe(†)

Contents

01. INTRODUCTION

Frode Nilsen
Arild Neby

Since the glaciers of the last ice age withdrew some 10,000 years ago and the human beings following the ice front first settled on the shores of what is today known as Norway, the utilisation of the underground space has been a necessity. People lived in rock caves or otherwise protected by rock for tens if not hundreds of generations. The main issue was protection from weather and wild animals. The several thousand year long occupancy of the caves indicates that maintenance has been a vital aspect of keeping these safe and secure.

With the mining industry's arrival to Norway from Germany in the 17th century, new ways of creating and utilising underground openings were introduced. During the last 120 years or so, the concepts for the use of the underground have further developed. First the rock mass was utilised for fortification purposes, railway tunnels, road tunnels, hydropower development schemes, then water supply tunnels, storage facilities, treatment plants for water and sewage, communication centrals, car parking, sport arenas and more. New requirements for maintenance and safety have been implemented over the years, what was looked upon as safe before, may not be the same today.

The main concept for all Norwegian underground constructions has been and is still to utilise the rock mass as the main bearing construction material. By applying the necessary rock support adapted to the local rock mass quality, the rock itself becomes self-supporting and the most capable and competent building material around.

Dependent on the planned utilisation purpose and the designed life time expectation of the underground opening, the applied rock support and the infrastructure furnishing level may vary. In this publication experience from operation of a variety of sub-terrain projects will be presented and approaches and solutions to common challenges are addressed.

In Norway, standards and regulations govern construction design issues and safety aspects for the underground opening. Being a modern society where there are growing concerns related to the safety and security of the infrastructure system, new requirements are continuously implemented. Compliance with these requirements also for old underground structures has become a major issue. Considerations involving maintenance costs and lifetime expectancies are to a much larger degree than before implemented in the design of new projects.

Even in scarcely populated Norway, surface space is becoming a valuable resource forcing limitations on urban expansion. The environment needs to be protected and the aesthetics considered. Norwegian underground projects have shown an extremely good record in most of these important aspects and the concept of going underground instead of constructing an above-ground facility is often the preferred solution.

Norwegian engineers have, through over a century of underground space application, gained wide experience in underground construction for most utilisation purposes. This experience is a valuable asset for the planners and the owners, but also for the everyday users, the consumers and the public.

We indeed hope this publication can be a useful tool for all our colleagues owning, using or constructing tunnels and underground openings, and thus be a constructive contribution towards an ever more improved use of the underground. For further information please contact the Norwegian Tunnelling Society.

People lead technology

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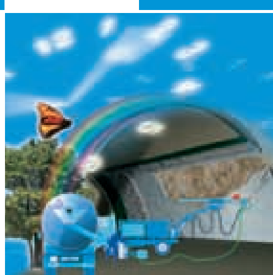
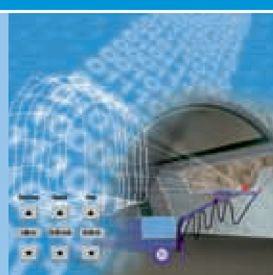
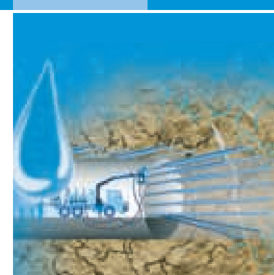
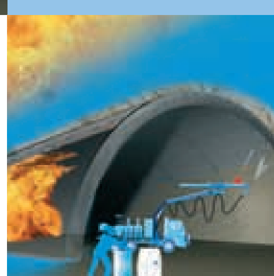
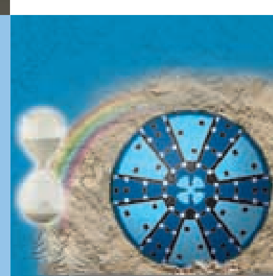
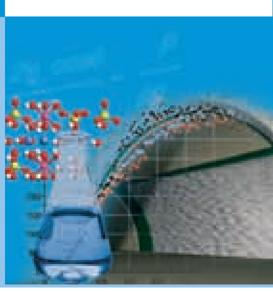

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02. THE USE OF THE UNDERGROUND

Knut Fossum
Espen Moe

INTRODUCTION

From schooldays and history we have learned that people at all times due to curiosity and necessity tried to explore and utilise the underground; from establishing shelters and protection, to the search for precious stones and minerals. This has developed into the constructions and facilities we see today, that - one may say - made the underground space available for common use.

Today one sees no limit to the variety of purposes for which underground structures can be established. The driving force is economy, a need for space, improved infrastructure, strategic points of view or security.

Time changes, new requirements and demands may cause necessary modifications to established structures. Old mines empty of minerals, may today be used for storage of difficult goods, radioactive elements, dangerous goods etc. A lot of effort is brought into research, the abandoned mines are already there, and many might fit well to such purposes.

Some basic ground conditions were required from the beginning, but today we see that the need for space has encouraged advanced technology to use weaker ground conditions. The competence and ability to solve problems like water leakage problems as inflow into tunnels and caverns, frost and earth quakes are available.

In view of safety one must accept different rules for underground constructions with public access compared to those excluded from public use or to those with limited access.

A general rule for all tunnels and caverns will have to be to limit the need for maintenance. This is often linked to ground conditions and the stability of the ground conditions. That again may be linked to water in the ground, as well as the need for additional rock support.

Today we divide the different installations into different areas and sectors, according to purpose

TUNNEL AND CAVERNS FOR INFRASTRUCTURE PURPOSES

Openings for infrastructure include road and rail, telecommunications, energy supply, sewage and water. For people to be connected, make use of their infrastructure and update their communication, tunnels and caverns underground have become increasingly more common. This also means that the purpose is to maintain the objective it has been built for. Maintenance, upgrading, improvements, enlargement and modernisation will be ongoing activities though.

The main issues and precautions to be taken into account for the different objectives vary according to the purpose of the construction:

Safety: All installations must be safe, however, safety precautions shall be modified in agreement with the conclusions in the consequence analysis. A rare block fall is completely unacceptable in say an underground cinema, whereas the same may be accepted in a water tunnel.

a **Road and rail tunnels. Complete safety,** at all times and for all users. This includes the general public, cars, buses, trucks and transport of people in general. They should not feel in danger at any time. Safety influence all involved, and people looking after the safety and inspection of tunnels must at all times have a main focus on safety and security for anyone inside or using the tunnel.

b **Water- and sewage tunnels and tunnels for hydropower plants,** require a lower level of safety and maintenance. These tunnels shall also be safe, but minor infrequent incidents are accepted. The frequency of inspection may also be reduced. Incidental reduced capacity may be accepted whereas full blockage is un-acceptable.

c **Water tunnels for hydro power plant.** Incidents like block fall may be accepted in the tunnels, but not in the main caverns, Full cave in of a water conduit would have a disastrous economical consequence for the owners. The consequence for the end-users of the electrical energy depends on the local grid etc. The tunnel will easy be emptied and inspected, and additional rock support work might be carried out.

d **Telecommunication tunnels,** are not meant for public use, but will require more frequent inspections than water and sewage tunnels. Problems due to rock engineering problems will not be tolerated.

e **Ventilation tunnels and others,** are as water and sewage tunnels not meant for public access. They may have combined uses, as emergency routes in case of accidents. This gives them a lower the level of safety compared to road tunnels

SPORTS HALLS, PARKING HOUSES, MIXED COMBINED CAVERNS FOR HUMAN ACTIVITIES

These complexes will often have mixed purposes. From being an alternative for the public, like schools, sports arrangements, shopping centres etc, they can serve as shelter for the public in times of war or threat of terrorist attacks.

Parking houses underground are a similar to sports halls in the sense that they can have a combined purpose. During the daytime, the caverns might be used for parking, and can easily be converted to a shelter in case of an external threat.

STORAGE OF FOOD AND GENERAL GOODS

Utilizing the underground as storage for food, water and other goods occurs more often in Norway than overseas. This has an increasing potential in the future. If we look at the need for clean water, storage of this in caverns underground can and might be a solution for many countries.

Depending on the kind of storage facility, it will probably be located near people, and used by people daily. That again requires that installation and rock support protective measurements have been implemented. The advantages of storing food or other goods underground can be many, but among one is the protective advantage. This applies mainly to storage in solid hard rock, but also for softer ground conditions similar advantages might occur. Rock support and tunnel safety are obvious requirements.

In Norway there are food storage in different parts of the country, and even freezing facilities for ice cream and frozen meat, has been stored underground.

The latest storage for the future is the seed bank in Spitsbergen, where millions of seeds from all over the world are stored for future generations. By that we, and the rest of the world will always have a safe deep freeze storage, located in an area of permafrost. The seeds represent our agricultural legacy for future generations, stored in a safe place for years to come.

TUNNELS AND CAVERNS FOR OIL AND GAS

This represents the industry with the highest growth rate, together with road- and railroad tunnels. The population has a need for safety as well as security. Storing oil or gas underground serves two purposes; firstly in hazardous situations, the population will with storage underground be protected and have safety, secondly the authorities have their expensive resource secured from unfriendly attacks.

The underground storage of oil and gas was a concept originally developed in Norway for landing oil and gas form the large producing fields off shore. Later, it showed its advantage economically and proved safe and secure, and the technology is now implemented in many countries. One of the latest developments is the technology used in Singapore.

For all these caverns, stability and optimizing width and height has been crucial. Financial calculations have shown that caverns underground for oil and gas storage are more economical than tank farms. This is interesting both for maintenance issues as well as protective issues. Maintenance here is difficult as the cavern will be fully operational at all times., The only possibility for proper inspection occurs when there is a change of product to be stored. A cavern might be converted form gas to liquid product, or from deep freezing temperatures to rock mass temperature. This might impose a change of the facility, and also a more intensive inspection and maintenance.

UNDERGROUND OPENINGS FOR STRATEGIC PURPOSES.

This sector includes civil protection, defence and other military purposes.

- Installations for storing energetic material and products
- Storing of machinery and equipment

- Commando and communication centres
- Coastal installations
- Workshops and more

The geological and rock engineering matters and construction principles for these installations are basically the same as for any other item. Demands to dimensions, rock support, access, portals are different from ordinary purposes.

SHELTERS FOR THE CIVILIAN POPULATION

Shelters for the civilian population during war time is of great importance. During a period of some 30 years from 1950 onwards the construction regulations required shelters to be be established in all larger residential buildings. Additional underground shelters were established by the communities paid for by national budgets. A number of the multidiscipline underground caverns utilised for sports today, were constructed under above mentioned regime. Politicians decided to cancel the programme assuming shelters are no longer important. That may be correct, at the same time a possibility to finance more underground sports arenas disappeared

QUALITY STANDARD FOR EQUIPMENT TO BE USED IN TUNNELS AND UNDERGROUND CAVERNS

Underground facilities must be equipped with ventilation and air conditioning units. Even so, equipment must be produced in agreement with adapted quality requirements. Special attention must be given to the electricity distribution net, to electronic equipment, any mechanical device and to surface treatment.

The advantage of utilizing the underground is obvious and the possibilities close to unlimited. Maintenance, however, must not be neglected. . From a rock safety point of view, inspection and control of the rock mass is important and necessary. Movements in the rock mass should be controlled under surveillance by means of online control devices

LNS - the mining- and tunnelcontractor from the arctic

Leonhard Nilsen & Sønner AS (LNS) was established in 1961, and the LNS-group consists of a total 14 companies. In 2007 the turnover was approximately NOK 1.1 billion (USD 210 million), and in 2008 the turnover is stipulated to NOK 1.5 billion (USD 286 million). The group's number of employees is about 800.

LNS main products are:

- Tunnels, caverns
- Mining contracts
- Rock support, grouting
- Earth moving
- Ready mixed concrete plant
- Production of modules and elements in wood

In 2007 LNS had the largest excavated underground volume by any Norwegian contractor. The last years LNS also has been engaged in Spitsbergen, all over Norway, Iceland, Russia, Greenland and the Antarctic. LNS has recently completed tunnelprojects in Lofast and Fjøsdalen in Lofoten, Svalbard Global Seed Vault in Spitzbergen, road and accesstunnel to opening a new graphite mine in Senja and two tunnels on the new highway E18 Tønsberg.

Some of LNS projects at the moment:

- Mining operations, Spitzbergen
- Mining operations for Elkem Tana, quartzite mine
- Mining operations for Fransefoss in Ballangen, limestone mine
- Ore handling, Narvik
- SILA, Narvik new harbour
- PPP E18 Kristiansand – Grimstad, 7 two-tubes tunnels of a new 4-lane motorway. Total length is 12 km
- Transfer tunnel, 7 km, Kvænangen Hydro Power Project
- Construction of a new main level for Rana Gruber AS iron ore mine

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LNS

03. ROAD TUNNELS IN NORWAY, A FIFTY YEAR EXPERIENCE From low cost, acceptable standards to modern tunnels of standards meeting the requirements of today.

Håvard Østlid

INTRODUCTION

The cost estimate of a tunnel alternative may be a major reason for not proceeding with a project, the cost is considered to be too high.
However, there are instances where tunnels may be built and maintained at much lower costs than generally known and accepted, these tunnels will have a comparatively low standard but still acceptable safety.
Examples of this are tunnels made for snow or rock avalanche protection, sometimes the only possible alternative protecting the road users .

This presentation is based on about 50 years of experience with tunnels of very variable standards, tunnels built and operated at low costs through developing special technologies and methods.

The standard of bridges, roads and tunnels undergo continuous changes in order to meet new requirements, these requirements may range from pure esthetical considerations to major changes in geometrical design.
Norway has a topography ranging from flat lowlands to very mountainous regions, with wide climatic changes throughout the year.
Summers may be very warm and winter may be very cold and in addition, the weather along the coast, strong winds and heavy rainfalls may be a challenge both for people and structures.
The total population of the country is about 4,5 million, the distance from north to south by road about 3000 km and large number of fjords are cutting deep into the country presenting great challenges in both bridge and tunnel engineering. In addition to this, ferries and their land structures also have to meet very high winds, waves and low temperature especially during the winter months.

Because people are living all over this big area and being relarively few, the demand for the cheapest possible solutions for both roads, bridges and tunnels became paramount.
Road tunnels were in very high demand as protection against snow avalanches and in unstable rock conditions and also as means of getting traffic through the high mountains in stead of a long and winding climb, crossing the mountains and a correspondingly long decent.

These conditions lead to the development of truly low cost tunnels, one had to build tunnels at very low cost but still with acceptable safety. The alternative was in may cases no tunnels at all.
The demand for tunnels from local people who had to travel to work through areas of constant threat of avalanches or sending their schoolchildren through the same areas every day was understandable to everybody.
The motif for constructing these tunnels became very strong.
Planning, building and maintaining a tunnel “ just good enough” is a formidable task, many elements have to be taken into account, sometimes the importance of some element were ignored or simply not understood at the time of planning or construction.
Later it became evident that smaller or bigger mistakes had been made and this was very important experience to be noted for use in future jobs.

After many years of planning, building and owning/ maintaining tunnels, Norwegian tunnel standards is mainly based on number of vehicles using the tunnel, at the time of construction and twenty years a head.
Low traffic flow has to accept narrower tunnels, steeper gradients, minimum lightening and perhaps also some visible water patches in the roof or on the walls.
Even if the tunnels are not looking very nice, the safety of the tunnels have to meet certain requirements, the safety inside the tunnels have to be just as high as on the outside road system.

These philosophies combined with many years of experience have lead to tunnels constructed for low traffic intensity in many comparatively remote places, enabling people to travel safely in spite of hazardous environments.

Site investigation may be performed on many levels, but even in this area it is possible to keep the cost down providing experienced tunnellers and geologists work together from an early stage in a project.

It is often said that in countries with very sound rock, which often is the case in Norway, it is easier to predict both technical problems and also financial overruns.
This is only partly true.
Case studies of tunnels passing through poor rock conditions have shown that provided experience is combined with geological knowledge and also a will to solve the problems, still produces tunnels with acceptable quality at surprisingly low costs.

Some examples will illustrate this:
A tunnel passing through reasonably good rock conditions, but with some poor areas now an then, may have a final cost of about Euro 10-11000 per meter, then everything is included, even water and frost protection .
The cost estimate of tunnels may be a major reason for not proceeding with a project, the cost is considered to be too high.

Comparing this to the cost of maintaining a winding road up and down a mountainside, and also have a permanent and safe road throughout the year may go a long way to offset the difference between the cost of the tunnel and the road in the open.

Fig. 1: Typical situation inside a Norwegian low traffic tunnel

The low cost tunnel shown in the photo is not very nice looking, but provides a safe and
reliable link with the other side of the mountain.
In practical everyday life, this is often more important than nice designs.

The road network in Norway has about 1000 tunnels ranging from very short tunnels to the longest road tunnel in the world, 24500 meters long.
The tunnel standards vary from very simple low cost, to standards meeting the requirements of today. Annual Average Daily Traffic may be as low as less than 1000 and up to a 100000 covering the whole range of low cost, low traffic to high cost, high traffic.

SOME DETAILS OF PLANNING AND INVESTIGATION

- Experienced personnel in this process is very important, "doing the right thing" could save a lot of money and problems both during construction and also during operation.

- The site investigation should be planned by using the experienced geologists preferably with experience in similar rock conditions. Placing of boreholes, recording, testing and reporting should be done by the same personnel and they should be attached to the project permanently during this phase.

- Experienced personnel in actual tunnel construction and maintenance should also play an important role in the planning process, all elements in the whole operation should be understood at this stage.

- The type of contract, selection of contractors etc., will not be discussed in this short presentation, however, this process may also be among the really important ones for getting a satisfactory result.

SOME DETAILS OF CONSTRUCTION

The drill and blast technology developed in Norway has been gradually and in phase
with the increasing demand for tunnels. Details of the methods used in all these operations may be found in many publications, some of the most important ones is listed at the end of this presentation. A very central publication can be found in Handbook 021 from the Norwegian Public Roads Administration (www.vegvesen.no), outlining standards, rules and regulations in detail.

SOME DETAILS OF MAINTENANCE AND REHABILITATION

An operational and maintenance function must contribute positively to the function of the tunnel in relation to the expenses that have been used. There is only one way the tunnel owner can contribute in this context, and that is availability = quality concerning the flow of traffic. An optimal effort is therefore required in order to accomplish this.

Conditions affecting tunnel maintenance are already determined from the moment the planning of the tunnel begins. Already in the early stages of planning, as one starts to describe the design of the tunnel, knowledge is needed about which conditions that can affect operation and maintenance.

The standards and solutions that are chosen will always influence future operational procedures and maintenance requirements. A tunnel will, in the same way as any other section of a road, go through different stages. Altogether this amounts to the total life span of the tunnel.

SOME WORDS OF WARNING

Owning and operating large number of tunnels of very variable standards facilitates
"learning by doing" in the real sense, many mistakes have been done over the years.
However, most mistakes have been recorded and remembered and then forms the basis for
a special database system produced and maintained by the Norwegian Public Roads Administration.
This is a system making it possible to find relevant information quickly and also identify experts in the actual field.

But admittedly, the best experience will be found in persons with many years of work in
planning, building and maintaining tunnels in practice. Combination of these two possibilities, the data based system and actual persons give the best possibility for good results.

SOME SIMPLE POINTS TO WATCH:

- Be very thorough in site investigations.This is normally a very cheap insurance.
- Make sure experienced people are staying with the projects till the end of the planning and construction phase. They should be involved in the daily routines in the tunnel production.
- Have future maintenance in mind all the time, select tunnel equipment and materials accordingly
- Pay special attention to tunnel entrances, keep climatic changes in mind

CONCLUSIONS

Road tunnels in Norway are built to standards mostly governed by traffic intensity, low volumes of traffic, low standards and high traffic intensity, high standards.
In both cases, safety and security are aimed at being the same inside the tunnels as on the outside roads.
The accident records over many tens of years also show this to be true, in fact, there are fewer accidents per length of road inside the tunnels than on the outside.

The difficult point is the change of standards between roads with low volume traffic to roads with high volume traffic.
Experience with Norwegian tunnels is that the forecasts in increase of traffic volume has been underestimated with the result of choosing too low standards on some tunnels.
This experience together with many other observations play an important role in future tunnel projects in Norway.

http://www.vegvesen.no
http://www.nff.no

04. ”BEING PREPARED” RULES AND CONSIDERATIONS ON HOW TO UNDERTAKE MAINTENANCE WORK IN VIEW OF LIFE CYCLE COST

Gunnar Gjæringen

INTRODUCTION

This paper is based on requirements as prepared by the Roads Authorities western Norway, for tunnel maintenance work contracted in the private sector. The requirements aim at covering best practise and methods of design for blasting work and rock support with a view to maintenance, safety, operation standard and the needs for inspections.
The maintenance contract system is based on quality requirements for agreed activities over a certain time period.

Tunnels are built in inhomogeneous material, in this country mainly in rock, a material that in some ways could be said being”alive”. The inhomogeneous rock mass is exposed to gravitational and/or tectonic stress. It is also frequently adversely influenced by water. Hence severe changes in the mass may take place. It is therefore advisable to analyse the potential risks and inherent consequences of such changes in a lifetime perspective.

Some factors are more important than others:

- The geological conditions and the predefinition of the rock
- The rock stress situation to expect
- Excavation methods
  - Drill & Blast
  - Full profile boring

Other aspects are (some of these are relevant for D&B only):

- The drill pattern
- Explosives, quality and quantity
- Sealing and pre-grouting
- The methods of scaling and bolting
- The necessity of rock support by using sprayed concrete
- The tender format
- Competence of the contractors

It is important to achieve a smooth profile without establishing new cracks and increased risk for block fall requiring additional rock support. Accurate drilling is a prerequisite for acceptable results. Correct collaring and length of drilled holes are of utmost importance. For the contour holes (outer ring of holes) the importance of correct and cautious drilling must be underlined. For normal rock quality the pipes from the drilling should be seen after the blast in the entire tunnel surface, from the lowest point of the wall on one side, in the roof and to the lowest point of the wall on the other side.
To obtain such smooth surface of the rock one should consider drilling a second ring of holes close to the outer ring, both with spacing of not more than 30 cm (one foot), while charging the outer ring using reduced quantity of explosives only. This approach will reduce the blast-induced cracks. The necessity of scaling, bolting and the use of sprayed concrete will be reduced. Water leakage problems will also decrease.
For road tunnels with low traffic density one may sometimes accept tunnels to open for general operation without any kind of concrete support.
In tunnels where the pipes from the drilling are seen across the entire area of a blast, there will be little need of rock support. The tunnel stability is safeguarded with bolts and support due to any water leakage problems only

While considering the rock support, the time needed for maintenance and repair is one of the important aspects. The lesser time available for maintenance, the better quality of rock support is needed.

The necessity of inspection and the way the inspection should be executed depends on the geological conditions, the rock support and the amount of traffic in the tunnel.
To avoid rock debris falling down into the driving lanes in the tunnel while open for traffic is of paramount importance.

1.MAINTENANCE OF STABILITY, SAFETY PRECAUTIONS, WATER AND FROST SAFETY MEASURES, SUPERSTRUCTURES ETC.

ADVICE:
CAUTIOUS CONTROL THROUGH INSPECTIONS!
REPORT TO THE RESPONSIBLE UNIT!

The following work routines should be followed:

BEFORE STARTING THE ACTUAL WORK:

- Carefully plan and organize the task, prepare a written risk assessment and share content with the crew. The crew must have documented competence of working in tunnels.
- Advice on equipment that should be used.
- The necessary protective equipment and tools to be used.
- Prepare appropriate warning signs / notification plans that must be approved by the owner.
- Go through the safety routines and activate the necessary sign plans.
- VTS should be notified. Rescue operation units should be notified if necessary.

THE ACTUAL WORK:

- The inspection concerns everything that is connected to the tunnel vault.
- The elements that are dealt with are: the rock mass, concrete structures like vault (roof), Invert slab , portals, PE-foam, fire protected PE-foam, bolts, sprayed concrete or other safety measures.
- The inspection should clarify whether there are changes in the above mentioned elements.
- It should immediately be reported to the owner if changes like this are discovered.
- Other possible measures should be assessed by the probability of a further adverse development, and the consequences of such a development would be.
- Areas where one must implement protective measures must be marked and stated according to the road identification system.

AFTER THE WORK IS COMPLETED

- VTS and other units must be notified when the work is completed
- A work rapport must be handed over to the contract partner (usually the owner) to be submitted to *Plania*

Type of road	Interval	Notes
E-roads AADT>5000	Twice a year	• Main inspection conducted after a complete wash. 2nd inspection after ½ year
E-roads AADT<5000	Once a year	• Main inspection conducted after a complete wash.
R-roads AADT>5000	Twice a year	• Main inspection conducted after a complete wash. 2nd inspection after ½ year
R-roads AADT<5000	Once a year	• Main inspection conducted after a complete wash.
F-roads AADT>5000	Twice a year	• Main inspection conducted after a complete wash. 2nd inspection after ½ year
F-roads AADT<5000	Once a year	• Main inspection conducted after a complete wash.

2.MAINTENANCE WORK AFTER ROCK DEBRIS DOWNFALL AND CHANGED CONDITION

WORK DESCRIPTION:

During the routine inspection of the network of roads, the contractor should immediately register and report any change of conditions or dangers that are about to arise. The contractor should, within the scope of the contract (maintenance contract for a certain period of time, frequently 3 years), secure the safety of road-users and road elements as per contract provisions. For minor incidents this means clearing the road / the area etc. controlling and possibly improving the actual objects in order to maintain traffic safety and prevent further damage of objects.

In the case of extensive damage, immediately to secure road-users, attempt to stop further development of the damage and to report to the responsible authority.

Systematic clearing and improvements are usually described separately.

BEFORE STARTING THE ACTUAL WORK:

- Carefully plan and organize the task, prepare a written risk assessment and share this with the crew. The crew must have documented competence of working in tunnels.
- Advice on equipment that should be used.
- The necessary protective equipment / tools that must be used.
- Prepare warning signs / notification plans that must be approved by the owner.
- Go through the safety routines and activate the necessary sign plans.

- VTS (Vehicle Transport Services) should be notified. Rescue operation units should be notified if necessary.

THE ACTUAL WORK:

- The inspection concerns everything connected to water and frost safety measures.
- The elements that are dealt with are: rock mass, concrete vault, other concrete elements, portals, PE-foam, fire protected PE-foam, bolts, sprayed concrete and other safety measures.
- The initial functionality should be maintained
- The inspection should clarify any changes in the above mentioned elements.
- Observed deviations should immediately be reported to the owner. Other possible measures should be assessed by the probability of a further negative development, and how great the consequences of such a development would be.
- Areas where one must initiate measures must be marked and stated according to the road identification system.

AFTER THE WORK IS COMPLETED

- VTS and other units must be notified when the work is completed
- A work rapport must be handed over to the owner for him to submit to internal management systems. (In Norway the road authorities have implemented "*Plania", a data program for road management and operation).*

3. PHYSICAL DESIGN IF NECESSARY BECAUSE OF DOWNFALL

- Carefully plan and organize the task, prepare a written risk assessment and share observations with the crew. The crew must have documented competence of working in tunnels.
- Advice on equipment that should be used.
- The necessary protective equipment / tools must be used.
- Prepare signs / notification plans that must be approved by the owner.
- Go through the safety routines and activate the necessary sign plans.
- VTS should be notified. Rescue operation units should be notified if necessary.

THE ACTUAL WORK:

- Conduct an inspection of the area in question.
- Establish a plan.
- Secure the area.
- Work your way in to the actual area from your safe position, always on alert and always from a direction where safe escape is secured. Loose rocks should be scaled off or supported by bolts.
- Loose bolts or water safety measures should be adjusted, fastened or fixed. If necessary, the owner should be called in to decide which measures should be taken.
- The elements that are dealt with are: the rock mass, concrete vault, slabs, portals, PE-foam, fire protected PE-foam, bolts, sprayed concrete and other safety measures.
- Other possible measures should be assessed, the probability of a further adverse development considered and the consequences of such development discussed.
- Areas where one must initiate protective measures must be marked and reported according to provisions in the road identification system.

AFTER THE WORK IS COMPLETED

- VTS and other units must be notified when the work is completed
- A work rapport must be handed over to the owner for him to submit to *Plain*

4. SCALING

- Carefully plan and organize the task, prepare a written risk assessment and share this with the crew. The crew must have documented competence of working in tunnels.
- Advice on equipment that should be used.
- The necessary protective equipment / tools must be used.
- Prepare signs / notification plans that must be approved by the owner.
- Go through the safety routines and activate the necessary sign plans.
- VTS should be notified. Rescue operation units should be notified if necessary.

THE ACTUAL WORK:

- The work should start at the end of the tunnel and then work its way along
- The work starts in the tunnel roof / slope and then proceeds to the walls
- All loose items are removed by bar scaling.
- Needs for bolts are marked
- Needs for other safety measures like sprayed concrete etc are also marked
- The elements that are dealt with are: rock mass, concrete vault, slab portals, PE-foam, fire protected

PE-foam, bolts, sprayed concrete and other safety measures.
- The inspection should clarify whether there are changes in the above mentioned elements.
- It should immediately be reported to the owner if changes like this are discovered.
- Other possible measures should be assessed by the probability of a further adverse development, and how the consequences of such development would be.
- Areas where one must initiate measures must be marked and stated according to road identification system. Visual controls are conducted for other safety measures, including the vault.

AFTER THE WORK IS COMPLETED

- VTS and other units must be notified when the work is completed
- A work rapport must be handed over for the owner to submit to *Plania (a data program for managing and operation).*

5. BOLTING

BEFORE STARTING THE ACTUAL WORK:

- Carefully plan and organize the task, prepare a written risk assessment and share this with the crew. The crew must have documented competence of working in mountain tunnels.
- Advice on equipment that should be used.
- The necessary protective equipment / tools must be used.
- Prepare signs / notification plans that must be approved by the owner.
- Go through the safety routines and activate the necessary sign plans.
- VTS should be notified. Rescue operation units should be notified if necessary.

THE ACTUAL WORK:

- The work comprises everything that has to do with bolting.
- The element that is dealt with is: The rock mass. Where to apply bolts, methods, makes, lengths etc should be agreed with the contract partner before the work starts.
- Possible process modifications should be reported immediately.
- Other protective measures should be assessed in view of the actual situation, probability of adverse development and the consequences of such development
- Areas where one must initiate measures must be marked and stated according to the road identification system.

AFTER THE WORK IS COMPLETED: AS PER ITEM

- VTS and other units must be notified when the work is completed
- A work rapport must be handed over to the owner to be submitted to *Plania (a data program for managing and operation).*

6. REPORTS.

The contractor shall prepare status reports that cover all work items executed during the actual period. Requested data include place, time and scope of executed work. Additionally the report shall describe the status of the tunnel elements like rock mass, bolts, concrete in general, sprayed concrete, portals, any water protection elements, safety and fire protection elements. All reports shall be prepared in format as per contract.

The frequency of reports shall be agreed as part of the contract. It may be advisable to agree on weekly and seasonal reports, say every six months.

The semi-annual reports should also indicate the status of the various tunnel elements (Rock mass, bolts, concrete elements, portals, water protection elements, safety installations and the sprayed concrete and fire protection measures.

Special reports must be prepared for damages and also if there is serious change in functionality or observation of stability problems, serious malfunction of machinery for the operation of the actual tunnels.

05. REQUIREMENTS FOR OPEN TUNNEL – AVAILABILITY

Harald Buvik and Gunnar Gjæringen

Fig.1 Portal of a Tunnel showing the barrier for closing the tunnel

INTRODUCTION

It is important to decide for how long it is acceptable to close a tunnel caused by planned maitenance work. The Road Authorities have prepared draft requirements of acceptable closed-down-time in view of tunnel class, from class A to class F.

GENERAL REQUIREMENTS

The safety level in a tunnel should be on the same level as for the adjacent stretch of road. The regularity should in a normal situation be 100%, except for the closing times due to planned maintenance.

One of the most important factors that safeguards the security and the regularity is the use of a documented, structured and systematic operating- and maintenance scheme. The following requirements should apply:

- Road-users safety
- The safety of employees
- The best possible flow of traffic = the greatest possible regularity

Critical conditions needed to meet these requirements will be reliable energy supply and communication systems both from and into the tunnel, and internally within the tunnel.

An absolute requirement for the supply of energy is 100% regularity. To achieve this, defined demands must be made on both the power supplier and to the owner of the transmission lines / mains . Binding contracts must be entered into. The supply of power can for example be provided by two different suppliers, or the delivery is provided by one supplier, but to both tunnel openings, also with ring supply if possible.

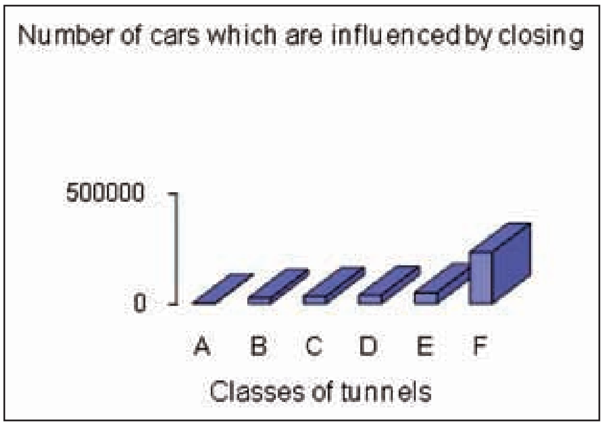


Fig.2 Accepted closing time for a tunnel depending on class of tunnel (see figure longer back in the article)

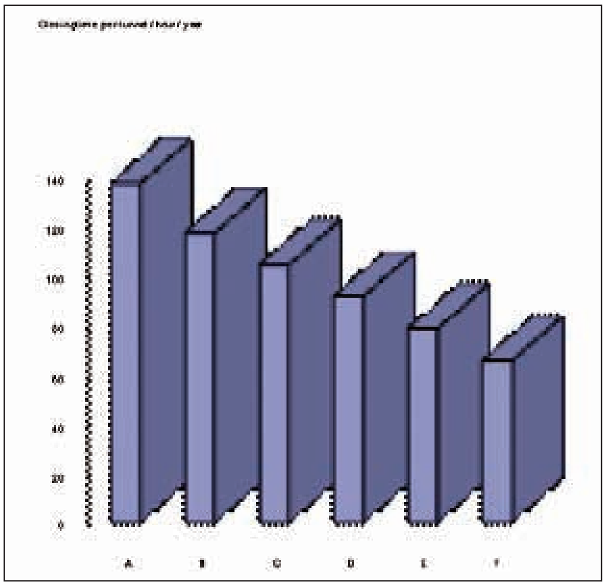


Fig.3 Tunnel closing time according to class of tunnel

When it comes to the communication systems, binding contracts must also be entered into. It is important that the agency has the expertise to follow up in the operating phase and that all provisions in the agreements are met.

The requirement will be 100% regularity in order to control and monitor the various elements that have to do with tunnel safety equipment. All service and planned operating and maintenance should be as frequent and universal that a technical failure will not occur as a result of insufficient maintenance. Maintenance and management routines should inform and ensure safety with regard to the function of the installed equipment and systems.

In the event of an accident or other unforeseen event the tunnel must be closed quickly so that rescue and evacuation can take place in a rapid and careful manner. The first rescue attempts should be able to be done by roadusers as well as the emergency services. It is thus important that the power supply and communications system are intact. The goal must be that the closing time of the tunnel is kept to a minimum and under all circumstances do not exceed the requirements stipulated.

Exercises are included in the sum hours for scheduled events.

SCHEDULED EVENTS

Accepted closing times in each class of tunnel

Classes of tunnels	**A** AADT 0 – 300	**B** AADT 300 – 5000	**C** AADT 5000 – 7500	**D** AADT 7500 - 10000	**E** AADT 10000 – 15000	**F** AADT > 15000
Accessibility	Accepts reduced accessibility 24 hours a day	Accepts reduced accessibility 24 hours a day	Accepts reduced accessibility in the evening/night	Accepts reduced accessibility at night	Accepts reduced accessibility at night	Accepts reduced accessibility at night
Closing	Can be completely or partially closed for up to 5 hours a day	Can be completely or partially closed for up to 2 hours in the daytime. In addition, can be completely or partially closed between 2100 and 0600	Can be completely or partially between 2100 and 0600. Opened every hour on the hour.	Can be completely or partially closed between 2200 and 0500. Opened every hour on the hour.	In a two lane tunnel, one lane is closed between 2200 and 0500. Demands a short diversion – or the use of the parallel lane in the tunnel or in the parallel tube.	One lane is closed between 2200 and 0500. Demands a short diversion - or the use of the parallel lane in the tunnel or in the parallel tube.
Reduced availability (100% is 8760 h/year)	Availability can be reduced for up to 1,5% (138hrs) pr. year pr. 3,0km tunnel length	Availability can be reduced for up to 1.35% (118hrs) pr. year pr. 3,0 km tunnel length.	Availability can be reduced for up to 1.20% (105 hrs) pr.year pr. 3,0 km tunnel length.	Availability can be reduced for up to 1.05% (92 hrs) pr. year pr. 3,0 km tunnel length.	Availability can be reduced for up to 0.90% (79 hrs) pr. year pr. 3,0 km tunnel length. .	Availability can be reduced for up to 0.75% (66 hrs) pr. year pr. 3,0 km tunnel length.
Notes	**I – II – III – IV- VI**	**I – II – III – IV- VI**	**I – II – III – IV - VI**	**I – II – III – IV – V- VI**	**II – III – IV – V - VI - VII**	**II – III – V – VI – VII**

Explanation of notes:	
	I = Emergency service vehicles can pass **II** = Information must be given to the press, prior to closure and at the point of closure. **III** = Local considerations must be safeguarded **IV** = Closure can mean: * Closed for the entire period * Opened every hour on the hour * Manual traffic control * Diversion if possible **V** = In the case of a parallel lane, it is closed where work is in progress - and the parallel tunnel is used to direct traffic in both directions. **VI** = Diversions should be notified and established **VII** = In tunnels with one way traffic, one of the lanes can be closed at any time of the day, except "the rush hour" - This requires a well established system with speed reduction and a clear distinction of driving directions. - The work is also carried out at the time of the year with the least amount of traffic.

Fig.4 Examples of the consequences / scope of the defined closing time

NON-SCHEDULED INCIDENTS AND ACCIDENTS

Non-scheduled incidents - Accidents			
CLASS OF TUNNEL A - F			
Incidents	**Causes**	**Requirements**	**Measures**
• Collisions • Crash • Fire • Explosion • Driving off the road • Work-related accident • Terrorism / Vandalism	➢ Poor visibility ➢ Blinded by sunlight ➢ Oil spill ➢ Slippery or wet road ➢ Animals in tunnel ➢ Loose objects on the road ➢ Explosion of dangerous goods ➢ Lightning ➢ Traffic congestion	The installed emergency equipment should be intact, operational and be able to be operated for at least 1 hour after the event or implemented closure.	Follow the procedures for the measures and the contingency plans which are made for each tunnel.

NON-SCHEDULED INCIDENTS TECHNICAL FAILURE

Non-scheduled incidents TECHNICAL FAILURE			
Point	**Tunnel classification**	**Requirements in accordance with tunnel classification**	**Measures in accordance with tunnel classification**
Power supply	**A - B - C - D - E - F**	Where applicable, the energy supply should be secured by an independent supply from both tunnel openings that are linked together in order to ensure a ring supply.	In the event of a power cut to tunnels without ring supply, a generator should be supplied as soon as possible.
Non-interrupted power supply	**A - B - C - D - E - F**	The uninterrupted power supply (batteries or generator) should give a minimum of 1-hours operation under the dimensional load for the installed safety equipment.	- Repairs/replacements of batteries or charge supply must be completed within an hour.
Lighting	**A - B - C - D - E - F**	In the event of a power cut, prioritised lighting (every fourth or fifth fitting) should function for about 1 hour.	Repairs should be completed within an hour. If the repair work takes longer, a charge supply must be provided to the prioritised lighting. At the prolonged loss of lighting, a trial run should be considered for class A tunnels. Diversions should be established for all other classes of tunnels.
Ventilation	**A - B - C - D - E - F**	The capacity and function of the plant should be big enough to allow for a failure of up to 10% without needing to close and evacuate the tunnel.	Repairs should be carried out immediately in the case of a failure of up to 10%. If the failure is more than 10%, the tunnel should be closed.
Lines of communication to and from the tunnel	**(A) B - C - D - E - F**	The lines should be intact at all times.	The tunnel should be closed and repairs should be carried out immediately.
Safety equipment	**B - C - D - E - F**	The plant should be connected to uninterruptible power supply that will provide min. 1-hour operation.	Repairs should be carried out immediately. Simultaneously, it should be considered whether the extent of the damage/ fault is such that the tunnel must be closed.
Fire extinguisher	**(A) B - C - D - E - F**	The apparatus should at all times be controlled and operational.	The apparatus is replaced.
Water- drainage system	**A - B - C - D - E - F**	Installations shall at all times satisfy the current requirements.	Repairs according to standard requirements in HB-021 and HB-111. Ref.:
Construction	**A - B - C - D - E - F**	Installations shall at all times satisfy the current requirements.	Repairs according to standard requirements in HB-021 and HB-111.Ref.:

THROUGH PLANNED MAINTENANCE SHUTDOWNS, THE LEVEL OF MAINTENANCE SHOULD NOT REQUIRE FURTHER REDUCTION OF ACCESSIBILITY.

06. MAINTAINANCE OF ROCK CAVERNS AND TUNNELS

Harald Pedersen

INTRODUCTION

Underground structures must sometimes be modified, enlarged or even converted for new purpose. Special aspects to be considered will frequently concern the ongoing operation, shut- down periods, safety and more. Very often existing facilities must be kept open, production may not be stopped and consequently the modification work must adapt to the given circumstances.

The work may be compared to a mining operation where production takes part, and at the same time they are developing new areas with excavation and blasting, which again means full rock support and inspection of the already operational construction:

- Rock support to be taken into a neat inspection during excavation and blasting.
- Monitoring.
- Ventilation
- Dust and toxically fumes.
- Shock waves during blasting

ROCK SUPPORT

When the further development of a rock cavern or the enlargement of a tunnel shall take place during ongoing operation, say "business as usual" in the existing construction, detailed planning, taking into account possible incidents due to the ongoing operation, must take place.

Hazards must be mapped and. Among the most important elements are the monitoring of the existing rock support and the planning of necessary additional rock support elements. A quality assurance plan must be prepared including a quality monitoring system.
Traditional rock support methods take place as sprayed concrete, rock bolts or in situ concrete lining.

MONITORING SYSTEMS

Among monitoring system, extensometers might be good solutions together with door stop methods and instruments monitoring shock waves. The defined acceptable level of shock waves will indicate the level and frequency of support control.

Ventilation Systems and Toxic fumes.
Ventilation during reconstruction/modification of en existing facility in full operation is complicated. The aim is satisfying ventilation for the ongoing operation and the construction work. Additional smoke, toxic gases, blast fumes from the construction work into the existing facilities must be avoided.

The blasting must take place in periods of little or no activity at all. It may be necessary to install temporary walls and/or increased air pressure in sections of the facilities.
Temporary working ventilation system might also interfere with the balanced ventilation system already in operation. That is why a physically separation of the working areas are to be preferred.

Shock Waves during blasting
A common problem is the shock waves during enlargements of tunnels of rock caverns. The shock waves depends on several factors, mainly from the quantity of explosives (the energy) fired on the same nos. of detonators. Depending of what kind of installations there are in the already operation construction, limitations is defined. Shock waves in a structure (of rock or concrete) will depend of the amount of already installed rock support as well as equipment or technical and mechanical installations in rock cavern or tunnel.

Most common installations are mechanical items fixed to rock or concrete structures. Hence the shock waves are directly transferred. Some items are less sensitive, others like fine instrumentation or computerized systems are extremely sensitive for vibrations like shock waves. Depending of the quality of the rock structure, competent or of a loose sedimetal rock structure, shock waves will have to be considered as an area of importance.

SOME PRACTICAL EXAMPLES

1. Veas, West Fjord Sewage Treatment Company

- In 1991- 1996 the treatment plant was enlarged with a new biological cleaning part, Separation of Nitrogen

This involved:

- Special blasting with care and very small amounts of explosive on each number of initiators and detonators. This was carried out very close to a plant that should be in operation running during the ongoing expansion work.

- It might create a more intensive rock support upfront and as well after the enlargement or expansion of the construction takes place. This is often depending of the rock structure and how the decline of the rock structure falls in.

This involved a:

- Lowering of all basements include pool, filled with sewage

- Existing concrete wall should remain during the whole construction period.

- The plant should be in full operation during the whole construction period.

2. Aurevann Water clean reservoir and plant

- The enlargement of the site took place from 1996-1999, and was rehabilitated in 2007- and 2008

- Blasting with great care in an existing plant, creating, constructing a new filter hall for cleaning.

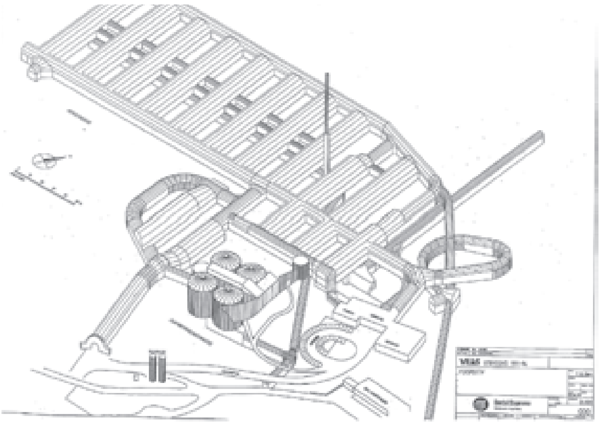
- Rehabilitation and construction of the already existing plant.

- Construction to take part without and interference of the operation and distribution of clean water to the municipality, Baerum.

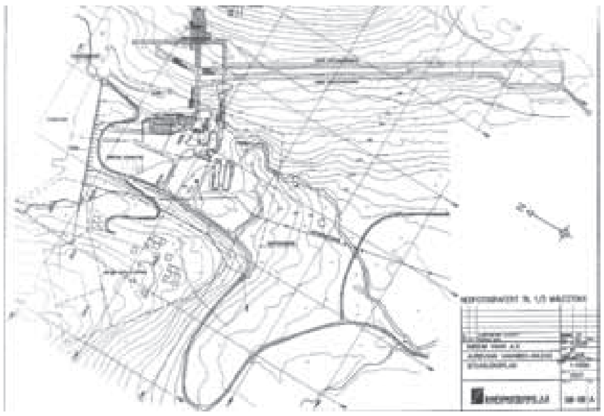
VEAS waste water treatment plant west of Oslo

Rock support outside new access. Also from the VEAS facilities.

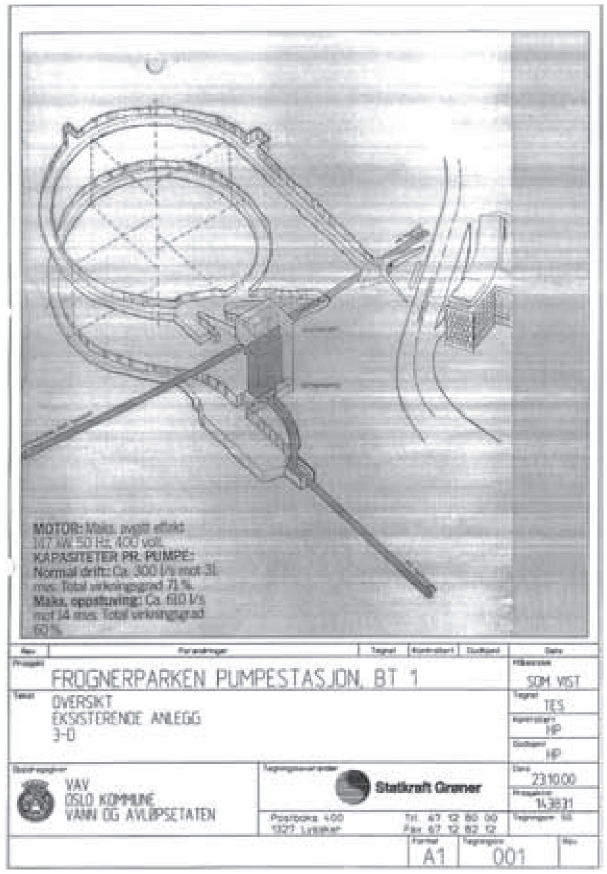
VEAS waste water treatment plant, from one of several caverns.



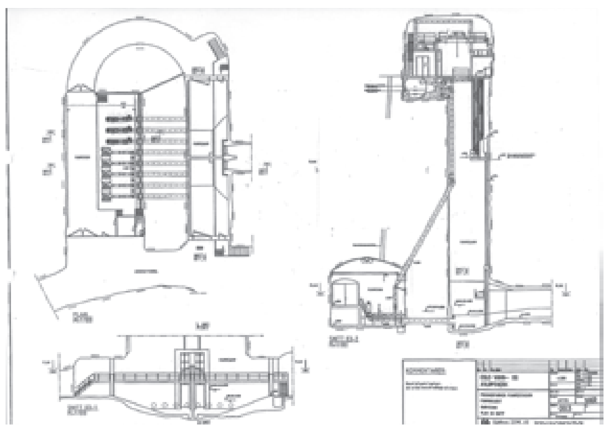
VEAS waste water treatment plant. General layout.



General layout of Aurevann facilities for potable water treatment.



Frognerparken pumping station. For waste water transfer to VEAS



Frognerparken pumping station. Cross section

3. Project samples of The Frogner park, pumping plant for sewage in Oslo

- Rehabilitation, construction from drowned pumps to dry placed pumps

•Blasting and construction of a new cavern for pumping of sewage.

•Blasting of a new emergency escape shaft.

•Installation of new inlet gates.

•Planning of the construction without any interruption of the running of the site and operation.

•Blasting of a new emergency escape shaft.

•Installation of new inlet gates.

•Planning of the construction without any interruption of the running of the site and operation.

Rescon Mapei - special products for tunnel and construction

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  - admixtures and accelerators for sprayed concrete
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  - micro cement, additives and chemical injektion
- **Fire protection**
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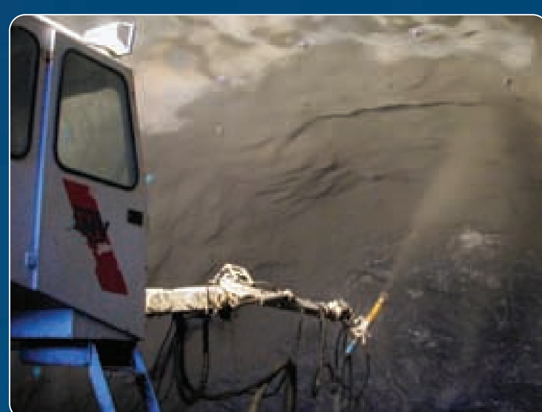
- **Surface treatment**
- **Installation of precast concrete elements**
  - elastic sealants
- **Fibres**
  - steel fibre, polypropylene fibre and macro fibre



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RESCON MAPEI

07. ROCK SUPPORT PHILOSOPHY IN VIEW OF LIFETIME CONSIDERATIONS

Jan K.G.Rohde

INTRODUCTION

In underground construction works there is a big difference in attitudes and strategies related to the rock support philosophy and lifetime considerations - from temporary mines and access tunnels to underground facilities for public use.

Essential questions within the rock support philosophy and strategy will be:

- What are the consequences of rock support failure?
- What is the lifetime of the underground facility?
- What is the lifetime of the rock support measures?
- What is the construction cost versus operational and maintenance costs?

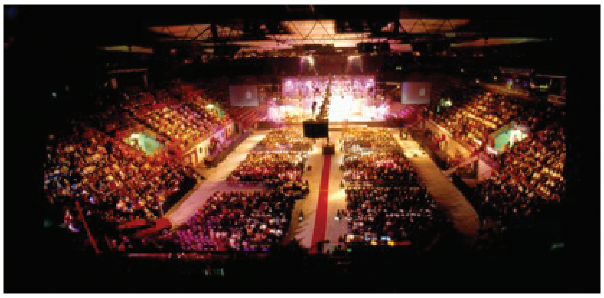
CONSEQUENCES AND ACCEPT CRITERIAS

In different underground facilities there will be different accept criteria depending on the consequences of rock support failures. The consequences and accept criterias of rock support failures are quite different for temporary access tunnels via water tunnels for different purposes to underground facilities for public use, strategic and defence facilities.

In the rock caverns for storage of industrial waste at the Boliden Odda facilities in the western part of Norway, there will be no persons operating inside the storage caverns during the operational period. The bedrock is of good quality and minor rock slides are accepted. The temporary rock support measures installed during the construction period are thus considered to be sufficient as permanent rock support.

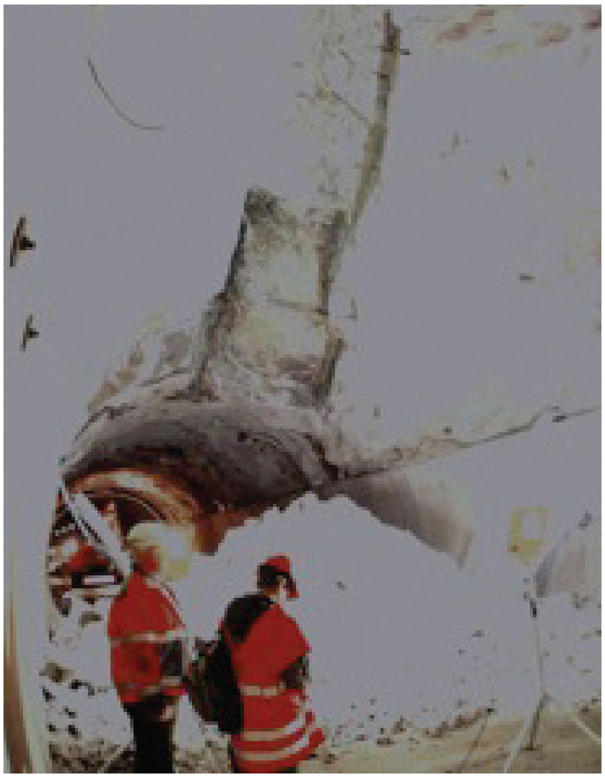
Drawing of the Boliden Rock Caverns for storage of industrial waste

The large rock cavern constructed at Gjøvik for hosting ice hockey matches during the Lillehammer Olympic Games in 1994 is still in use for sport activities. Consequences of rock support failures would be serious. The applied rock support philosophy had to be on the conservative and safe side: "Rock support failures are not accepted".



The Gjøvik Olympic Hall

The Hanekleiv highway tunnel in Vestfold, Norway, was opened in 1998. A serious failure and collapse of the rock support measures happened in desember 2006. Luckily, due to good timing, the collapse took place during the Christmas celebration, there was no traffic in the tunnel and the collapse was discovered before any accident happened. The consequences could have been tragic. The accept criteria for this type of tunnel is the zero vision - no accidents accepted.



Slide in the Hanekleiv tunnel

The rock cavern concept for storage of oil and gas is feasible provided good quality rock mass. Like for the storage caverns for industrial waste, minor rock slides might be accepted. Damage to vital structures or installations inside the caverns must however be avoided since damage will have serious consequences with loss of production and income. Access to the caverns in the operational period is very limited if possible at all.

Rock cavern for oil and gas storage

LIFETIME CONSIDERATIONS

Lifetime of temporary mine openings and access tunnels might vary from less than a year to some years or more, while traffic tunnels and underground facilities for public use might vary from 50 to more than 100 years. For some underground construction facilities like permanent underground storage of contaminated and nuclear waste, even the post closure stage must be considered. For some of these facilities lifetime of more than 1000 years might be relevant.

For the permanent storage of industrial waste at Boliden and the rock caverns for storage of low and medium radioactive waste at Himdalen in Norway, even the post closure stage had to be considered. The rock caverns including permanent rock support were designed for a period of more than 1000 years. Scenarios including operational accidents and human activities, sabotage and war plus natural events like earthquakes and long term climatic changes were included in the risk analysis and impact assessments.

The Himdalen Underground Storage of low and medium radioactive waste

The underground dry dock for maintenance and repair of navy vessels at Haakonsvern was completed in 1960. For maintenance of the new generation vessels delivered from 2006 onwards, the dry dock had to be extended in width and depth. Parts of the underground cavern were opened to give space for the new vessels. Thus, due to new requirements and need for rehabilitation, the lifetime of the old underground cavern was approximately 50 years.

The extended dry dock for the new navy vessels at Haakonsvern, Bergen

The Festningstunnelen, a double tube highway tunnel with three lanes in each tube under the Oslo city centre was completed in 1987. Due to high maintenance costs plus new safety and security requirements, the tunnel, after 20 years in operation, is now ready for rehabilitation.

The lifetime of rock support measures depends on the design, the selected type and the materials, the rock mass quality, the quality of performance and the workmanship during installation as well as the internal climatic conditions and the chemical environment in the underground facilities. In road tunnels and subsea road tunnels in particular, the environment might be very corrosive. Unprotected steel rock bolts may have a short lifetime. Road and railway tunnels will frequently be exposed to changing climatic conditions throughout the year, from warm and humid summers to cold winters with extreme frost and ice problems.

Rock bolts, sprayed concrete and concrete lining are the most common support measures used in underground caverns and tunnels. Today, there are materials, corrosion protection methods and additives that makes lifetime of 50 – 100 years or more possible for the common support measures. Good quality concrete lining will have a lifetime of several hundreds of years in normal climatic and chemical environments. In water tunnels for different purposes there are examples that even unprotected steel bolts have only surface corrosion after more than 50 years in operation. Even timber support might have a long lifetime like in the Emma Hjort water tunnel (a tunnel in the western suburbs of Oslo).

Emma Hjort tunnel for fresh and drain water pipes – timber support – although in poor condition, parts of the timber supports are still intact after more than 50 years in operation

Hydropower development in Norway started at the end of the 19th century. Many tunnels from the early period are still in operation.

The Bleikvatn – Røssvatn hydropower tunnel, transferring water from Lake Bleikvatn to Lake Røssvatn was completed in 1960. The tunnel is approximately 5000 m long, has a cross section of 7m2 and had a design capacity of 12 m3/sec. Due to collapses and slides, the capacity has gradually been decreased to 3 m3/sec. Today a new tunnel is constructed to replace the old one. In this case the lifetime of the old tunnel has been less than 50 years. The rock support measures were installed for the construction period only and there was probably no rock support strategy for the operational period.

The partly collapsed tunnel between the lakes Bleikvatn and Røssvatn was not accessible and subsea ROV vessels were used for inspection

The first stage of the Borregaard Hydropower Plant in Sarpsborg (100 km south of Oslo) was completed in 1906. Extensions took place in several steps until recently. The tunnel system was inspected for the first time in January 2008. The tunnel system including the concrete lining was in good condition. Necessary rehabilitation of the rock support was limited to scattered rock bolting. In this case, the lifetime of the rock support measures was more than 100 years.

Before the cofferdam was constructed, the old tailrace tunnel at Borregaard hydropower plant was filled with water

The Gausbu hydropower plant was completed in 1994 and inspected the first time in 2007. All rock support measures were in good condition except from one section where the shotcrete layer had cracked and a slide was in progress. At the time of inspection the slide occupied approximately 1/3 of the tunnel cross section. After a risk assessment it was decided to continue the operation of the plant and prepare for repair during spring/summer 2008. The slide was probably due to poor workmanship and lack of geological understanding during construction and implementation of the rock support. Lifetime of the rock support in this case was less than 14 years.

The slide in the Hanekleiv road tunnel allready mentioned, happendend after a period of tunnel construction with focus on cost, work progress and contractual matters while there was less focus on geological conditions, rock mass behaviour, design, quality and lifetime considerations of the rock support. In this case, the lifetime of the support measures was less than 5 years.

In many of the underground facilities, at least parts of the rock support measures will have a lifetime less than the lifetime of the facility itself. In those cases, inspection and maintenance of rock support measures must be included in the maintenance and operation routines of the underground facilities. If inspections are impossible during the operation period, the support measures must be designed for a lifetime not less than the operational lifetime of the underground facility itself.

Road and railway tunnels used to be inspected annually after the winter and frost season. Loose rock were removed and rock bolts or other support measures were installed as necessary. Today, these tunnels are lined with water and frost protection so the rock surface and rock support measures are more or less covered. Today, there are access possibilities behind the water and frost protection which allows for inspection. In modern highway tunnels inspections are performed every 5 years.

CONCLUDING REMARKS

For underground facilities there will be different philosophies and strategies depending on the consequences of rock support failure, lifetime of the underground facility and construction versus operational costs.

The quality and the costs for the installation of rock support measures must be evaluated versus the costs for the maintenance and rehabilitation of the rock support. Furthermore, the quality of methods and materials must be sufficient to keep the risk of rock support failure and safety for the users within acceptable limits.

In many projects there will be a compromise between the construction costs and the operation and maintenance costs – underground projects are no exemption in this respect. Unfortunately there are too often lack of focus on the maintenance and operational costs both during the design and the construction period.

Very often the tunnel owner's organisation is clearly divided between a planning division, a construction division and the operational division, sometimes even with separate budgets.

For better understanding and to select more optimal solutions a close cooperation between the different divisions is recommended – to involve the operational unit in planning and planners into the construction and operational stages. To find the optimal level of construction costs versus operational and maintenance costs, different models for life cycle cost analysis (LCCA) have been developed.

Build, Operate and Transfer (BOT) and Public, Private Partnership (PPP) contracts, where the constuction company or organisation will have responsibility for the detailed design, construction, maintenance and operation of the project have been developed to take better care of the long time planning, construction and operation of the project. Norwegian excamples are the E36 Klett – Bårdshaug highway (in operation) and the E18 Grimstad – Kristiansand highway (under construction).

For both projects, the Norwegian Public Roads Administration is the owner while the contractors will be responsible for the operation and maintenance of the projects including tunnels during an operation period of 30 years.

Rock support philosophy in view of lifetime considerations might be summarised as follows:

- Design of rock support must be based on geological conditions and rock mass quality
- Consequences of rock support failure must be considered, and must, as a minimum, be within acceptable limits for the users
- Life Cycle Cost (LCC) analysis is a useful tool to find the optimum rock support – often some extra costs during construction means savings in the long term
- Quality control, supervision and mapping of geology during construction are important – the rock masses plus rock support measures are the main construction material in rock tunnels and underground rock caverns
- If the expected lifetime of rock support measure is less than the lifetime of the underground facility, inspection routines and plans for rehabilitation should be incorporated in the operation manuals
- Geological reports and as built documentation of rock support measures are important tools for the operational and maintenance stage

08. DEGRADATION OF EARLIER REINFORCEMENT AND SUPPORT

Asbjørn Martiniussen

BACKGROUND

In many older Norwegian road tunnels more or less degradation of the rock support is experienced. There are 3 main reasons for this degradation:

1. Corrosion of various types of bolts and wire mesh
2. Deterioration of sprayed concrete
3. Unstable concrete structures, cast concrete tunnel arches and walls

INTRODUCTION

The environment in our road tunnels is highly corrosive, and it is probably worse than we thought until a few years ago. Corrosion and degradation of installations is a growing problem, in particular in tunnels subject to heavy traffic loads.

Corrosion occurs when there is ingress of air and water. In addition, there are a number of factors that affect and accelerate the corrosion process.

Air pollution is a major factor that comes from:

- Exhaust from the traffic
- Location
  - Coastal climate
  - Inland climate
  - Towns – high traffic load
  - Industrial pollution
  - Low traffic load

Other factors may be:

- Effect of seawater (subsea tunnels)
- Effect of rock types in the tunnel (siliceous rocks often give rise to corrosion)
- Effect of temperature (freezing/thawing)

In addition, damage can be seen as a result of:

- Wrong choice of materials
- Inadequate structural solutions
- Choice of inappropriate maintenance methods, for instance:
  - Use of magnesium salt for dust suppression
  - Inadequate cleaning
  - These poor choices come from the failure to take into account the aggressive environment found in tunnels.

BOLTS, STEEL STRAPS AND WIRE MESH

Since the 1950s it has been common practice in Norway to use rocks bolts, steel straps and wire mesh for the reinforcement of rock tunnels, caverns and other underground openings. At first, bolts without special corrosion protection, so-called "black bolts", were used. These bolts were end-anchored clevis bolts or cotter bolts. They provided rather insecure anchoring and were phased out in favour of expansion bolts and later fully embedded bolts or end-anchored bolts, anchored in grout or polyester resin. From about 1970 it became standard practice to use corrosion-protected bolts for permanent reinforcement, but the black bolt was still used to some extent as working reinforcement. This was also the case with steel straps and wire mesh. Also, until about only 25 years ago cotter bolts were used as installation bolts for water and frost protection.

After 50 years' experience with this method of protection, which includes 15 years' use of the black bolt and 35 years' use of hot-dip galvanised bolts, a number of conclusions can be drawn.

Old end-anchored black bolts are no longer of any value. These bolts have in general poor anchoring and no longer serve any purpose. Bearing plates, nuts and the part of the bolt projecting from the bolt hole are highly corroded. However, where there is no water in the bolt hole, little corrosion can be seen on the rest of the bolt.

This is also true in the case of tunnels where traffic levels are low and environmental stresses are considered small.

On the other hand, fully embedded black bolts seem to perform well. Bearing plates, nuts and projecting bolt ends have corroded so much that often it is impossible to get a grip for pull testing equipment, but in the few cases where we have managed to conduct pull-out tests, the bolts seem to perform well. However, it is inadvisable to rely blindly on the performance of these bolts being adequate. We know that there may be faults in the grouting in the form of air pockets in the mortar or water that has washed away the mortar, which have a weakening effect on the bolt.

As for hot-dip galvanised bolts, research shows that they are normally very durable and long lasting. Hot-dip galvanised bolts in our first underwater tunnel, the Vardø tunnel, show no sign of corrosion even though they have been exposed to seawater and algae for 20 years.
Epoxy-coated and hot-dip galvanised bolts have been used for a number of years. Experience with bolts of this type is good, but they have been in use for too short a time to allow definite conclusions to be drawn.

Steel straps of the black variety have also become highly corroded. They lie freely exposed in the tunnel space and are subject to all environmental stresses. The hot-dip galvanised variety, on the other hand, seems to perform well.

Wire mesh was earlier used quite widely, and it can be see that braided wire mesh of different qualities has been used. Some perform well, but others can be torn down with cleaning irons or fall down of their own after 25-30 years.
The reason for this is that there have not been any set requirements for corrosion protection of the wire meshes, and therefore the cheapest and simplest quality has often been used. In recent years, plastic-coated wire mesh has been used in the belief that it will perform better. However, there is no guarantee of this if the wire is not hot-dip galvanised in addition. The use of wire mesh has gradually diminished, and when it is used today it is often sprayed concreted in place.

Various types of installation bolts for water and frost protection, fans, lighting, cable bridges and other installations are used in Norwegian tunnels. The choice of bolt types and corrosion protection for these installations should be at least as good as for rock reinforcement since these bolts are freely exposed to air and moisture. This has not always been the case and a good deal of unnecessary rust damage can be seen.

In places where non-corrosion protected rock reinforcement material has been used, there should be more scrupulous follow-up. Material of this kind that has been in place for 30-40 years may have lost its effect and new reinforcement will be required.

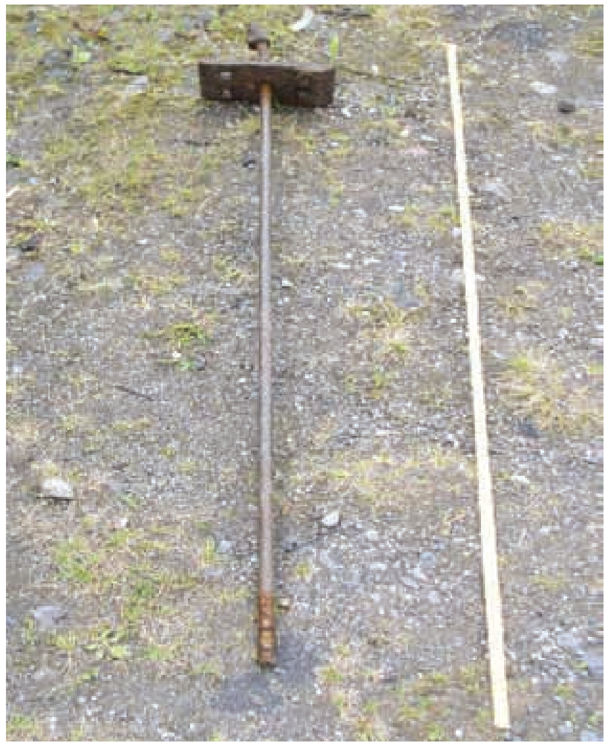


Figure 1: A 35-year-old black bolt used for working reinforcement

SPRAYED CONCRETE

In Norway there is almost 40 years' experience with sprayed concrete, and for rock support or reinforcement it is mainly fibre-reinforced sprayed concrete that has been used.
It appears that in an early phase thinner layers were used than is the case today. However, even today we find that too thin layers are applied, and we also see poor results from faulty sprayed concrete work. These are factors that have significance for the lifetime of the sprayed concrete and for its effect as rock support.
The sprayed concrete will often flake where the layers are too thin, ie, where there is a thickness of less 3-4 cm. The flaking often occurs in the transition between a sprayed concreted and non-sprayed concreted section.

There may be several reasons for this:

- Poorly cleaned rock face
- Water combined with freezing/thawing processes
- Chloride penetration which causes corrosion of fibres, perhaps particularly relevant in the case of underwater tunnels.
- Other environmental stresses

As a main conclusion, it seems that where the layers are of sufficient thickness and where the work has been done well, the sprayed concrete performs well.

Some lime deposits are likely to occur and shrinkage cracks may develop in the sprayed concrete. It is not known what the long-term consequences of this will be.

Figure 2: A 25-year-old wire mesh, completely corroded.
An attempt has later been made to repair the damage using new wire mesh and steel straps.

In general, there are few weaknesses with sprayed concrete. On closer investigation, there is just as likely to be faults in the rock behind as in the sprayed concrete.

CONCRETE STRUCTURES

In connection with Norwegian tunnels, primarily the following concrete structures can be found:

- Portals and avalanche canopies
- In-situ concreted structures and walls inside the tunnel
- Fully grouted tunnel profiles

In general there is little damage to these concrete structures.

Damage to portals occurs as a result of rock fall impact on the portal. Quite often water leakages in the concrete joints can be found. There is also some damage as a result of a lack of reinforcement cover where the reinforcement is rusty and has cracked loose the concrete, partly because of chloride penetration. Lime deposits also occur.

Where full grouting has been carried out, we find a number of defects as a result of the workmanship. It is difficult to check the grouting behind the casting shield, and therefore some honeycombing and grouting of varying thickness overlying the rock can be seen. We also find that rock falls have occurred during grouting and are visible in the concrete facing into the tunnel space. It would seem that it has been a problem to obtain sufficient thickness of the concrete in the roof, especially in older structures. Most of the damage that can be seen on the concrete structures can be traced to defects in the workmanship.

09. POST-GROUTING

Per Heimli

THE REASON FOR POST-GROUTING

This article deals with post-grouting and injection of fissures and joints in unlined rock tunnels. Injection of water leakages in lining systems are therefore not covered.

The concept of post-grouting of unlined rock implies that intolerable water ingress for various reasons is experienced in a tunnel. Rather than dealing with sudden water break-ins at the tunnel face this article describes some principles and methods that can be applied behind the face. It is important to notice that the method of grouting unlined rock should not be applied where a completely water-tight tunnel is demanded. It that case some type of lining should be considered.

Post-grouting works come to effect when ordinary pre-grouting procedures have not given the expected result, or when grouting has not been performed at all during excavation. The magnitude of water leakages is frequently intolerable because of unacceptable lowering of the groundwater. Another reason for post-grouting is often that the water leakages are a threat to the structures inside the tunnel, or that the pumping costs are considerable. In some cases also a costly water treatment process may call for post-grouting. Water leakages may in some occasions also cause harmful effects caused by detoriation of bedrock formations containing water-soluble minerals like anhydrite.

It should also be noted that in cold climates even small leakages may cause great trouble because of ice formation.

For all who has been dealing with grouting it is obvious that post-grouting is some kind of emergency solution because the conditions during grouting ahead of the tunnel face is far easier to deal with. In the post-grouting process one frequently has to conquer water flows that tend to flush the grouting agent back into the tunnel, in the contrary to pre-grouting when the water conduits are penetrated before the water percolation enter the excavated tunnel.

Unacceptable leakages may be caused either by large, concentrated leakages, or by rather small leakages, often evenly distributed along the tunnel. These two scenarios may call for quite different remedial measures. Experience from different tunnels show that concentrated leakages tend to stay permanent or even increase by time when a sufficient water reservoir is available. Small-scale leakages by the contrary sometimes have a tendency to be self-sealing. This can be caused by natural clogging by particles in the water, or a slow precipitation of minerals on the joint surfaces, such as carbonates and iron oxides. Theses processes are more pronounced in tunnels where pre-grouting with cement-based agents have taken place.

DRILLING OF HOLES

The drilling pattern for grout holes may vary considerably, from a few holes drilled in order to penetrate the conduits behind concentrated leakages, to more evenly spaced holes around the tunnel periphery in order to reduce a more diffuse leakage pattern. It is often experienced that it may be rather difficult to get a direct hit on the conduits with a borehole some distance from the tunnel wall. This is because the conduits routinely are unevenly distributed, and bending in various directions. A large number of holes will therefore frequently be needed before the grouting can take place. A successful grouting of a concentrated leakage will, however, quite often result in the formation of a new leakage in a nearby part of the tunnel, and one has to start all over again. In the long run it is often better to spend some extra time for the drilling of a defined hole pattern also to each side of the leakage before grouting is commenced.

When post-grouting is needed after a pre-grouting scheme has been used, it is often prudent to drill a fan of holes in the opposite direction of the pre-grouting fan, possibly with some adjustment for the orientation of the main rock structure, e.g. the bedding orientation of a sedimentary rock.

GROUTING PRESSURE AND METHODS

A main disadvantage in all post-grouting operations is that the applied grouting pressure quite frequently has to be considerably lower than that of the pre-grouting. This will often call for different grouting agents and techniques. Everyone who has performed post-grouting has experienced return of the grout agent at the rock face. The reason for this may be multiple: inadequately long setting time of cement based grout, insufficient mix or dilution of two-component agents caused by water flow, introduction of the grout too close to the tunnel, or sometimes also application of too large pressure (causing hydrofracturing of the rock). These features make it almost impossible to define a set of pre-defined stop criteria like a maximum grout take or pressure, which is often found in pre-grouting specifications. A post-grouting operation is therefore strongly dependent on skilled specialists who has the ability to decide what the next step will be, choosing the right alternative for the actual situation.

To stop a grout return can often be a frustrating task, where different methods can be involved. In situations where water ingress at the actual location is no problem, the use of different additives to give an almost instant reaction in a cement-based grout is widely used, but this will often result in a clogged hole without a significant effect on the leakage. It is also possible to use grout with aggregates in order to gradually clog up the leakage. An alternative to this is to use water-reactive polyurethane where the foam will create a barrier for later application of pressure grouting. In this context one should not forget the "old fashioned" method of sealing the fracture opening with wooden wedges and oakum. It is a time consuming operation, but it is usually very effective.

GROUTING AGENTS

The grouting agents used for post-grouting are more or less the same as for ordinary grouting, which means that cement based grouts are widely used. The cement types are either fine ground with a d95 in the region of 35 – 40 μm, or the so called micro cement types, typically with d95 of 12 – 15 μm. Regardless of fineness it is important that the cement grout is stable (without significant bleeding), and gains a decent strength after relatively short time. This is only achieved by using additives and a low water/cement ratio. A very effective additive for ordinary fine ground cement is micro silica which makes the grout thixotropic, a valuable quality when it comes to grouting. The addition of micro silica to micro cements should be used with great care as these cement types are chemically more active than ordinary cement types.

During the years a great variety of so called chemical agents have been used in all types of grouting, mainly in situations where the joints are too narrow to be penetrated by cement based grouts. During the latest decade, however, a lot of these types, e.g. acrylamides, have been banned in many countries because of known and/or suspected harmful health and environmental properties. Especially during post-grouting operations these considerations are relevant because most of the chemical grouting agents are two-component, where at least one of the components may be very poisonous. Spill of components and return of poorly reacted agents will inevitably cause harmful concentrations in the tunnel's drainwater system.

Well-known agents which are less harmful are different gel types, like sodium silicates with the addition of harderner. A disadvantage is often that they suffer from syneresis and failing long term stability.

A relatively new agent with promising properties is based on colloidal silica, known as silica sol, which is a Newton fluid with a viscosity close to water. It forms a stable dispersion of discrete nonporous particles of amorphous SiO2. The particle size is in the order of 10 nm. The particles aggregate and form a solid gel at a pre-defined set time, which is controlled with the addition of salt (NaCl or CaCl2). Relatively long time tests (more than 10 years) have shown that this gel is impermeable and durable. Colloidal silica seems to be a feasible agent to seal very small joints, <0.05 mm.

"NATURAL" GROUTING

In situations where a slow grouting effect can be tolerated some more exotic methods may be tried. These are methods that to some degree mimic the natural mineralization processes that take place in rock joints and fractures.

It is in some cases observed that groundwater with a high content of bivalent iron will tend to oxidize to trivalent when sufficient oxygen is present, thereby forming precipitates of oxides and hydroxides of iron. When a relatively high content of iron in the groundwater is present it should therefore be possible to form particular, trivalent iron by injection of oxygen rich water in the rock mass. This will probably have some effect only when the leakages are relatively small.

HSE ASPECTS

The HSE aspects regarding the grouting agents and the grouting process are the same as for ordinary pre-grouting, and will not be dealt with here. The possibility of spill to the tunnel drainage system is, however, far more pronounced during post-grouting, and should be subject to special concern. This applies both to the high alkalinity caused by cement, and to the toxicity caused by un-reacted chemical compounds. The potential for the emission of harmful smoke in the case of fire in a tunnel can be regarded as negligible because of the small joint volumes affected in a fire.

10. GEOLOGICAL INSTABILITY AND PROBLEM AREAS

Per Bollingmo

Geological instable and problem areas are sometimes a reason for rehabiltation demands.

Generally spoken, water is involved in many problems for underground constructions, not only as leakage or water pressure, but mostly as an important part in geological processes, such as weathering and chemically altering of minerals.

Here, some geological features as important reasons for rehabilitation and maintenance are described:

ROCK STRESS

Rock stress may cause spalling, rock burst and unstable rock contours. Normally these effects are lasting for some hours, up to months, but can sometimes continue over years. A flexible initial rock support allowing some deformations is preferable. Rock bolts and shotcrete have proved effective in many cases, but also heavier support may be needed.

Rock stress in combination with very weak rocks can appear as squeesing rock, which normally will require heavy rock support. Underestimation of the forces involved has several times caused collapse of support constructions.

CRUSHED AND HEAVILY FRACTURED ZONES

These are encountered in nearly every underground construction, and are treated with conventional supporting measures, such as rock bolts, shotcrete and concrete lining. Normally there are few problems in establishing a satisfactory support against these phenomena.

WEATHERED AND CHEMICALLY INSTABLE ROCKS

Weathering and chemically instable minerals are phenomena that may cause stability problems over long periods of time.

Weathering and alteration of minerals are one of the main reasons for underestimation of forces on support constructions, and have often lead to collapse or rehabilitation demands of underground constructions. The most common phenomena are described below:

SWELLING CLAY

Weathering and altering of minerals to smectites with swelling properties is a common problem. Laboratory testing of the potential swelling capacity of clays in oedometer will only give indications of the in situ pressure on a support construction. This must be supplemented with engineering geological evaluations, taking into account the width and the orientation of clay infected zones, and also the size of the actual tunnel.

The geological processes include moisturing of the clay minerals through water seepage and/or from a moist atmosphere. The processes can be very slow, and collapse is experienced in tunnelling projects more than 10 years after construction.

Not only swelling pressure is a reason for problems with clay materials in clay zones. Clay infected zones may also reduce internal friction properties when moisten, and thereby enforce heavy loads and collapse of the rock support.

ALUM SHALE

Alum shale is a common problem in certain areas. The shale is containing sulphates, and is through weathering, producing sulphuric acidic solutions harmful to concrete. Proper concrete mix using waterproof high strength concrete, and/or sulphate resistant cement will protect against concrete deterioration.

The weathering processes also produce expanding sulphate minerals, introducing a swelling pressure in the rock. These processes are proved to continue for decades, and heave of floors founded on alum shale are reported to more than 0.5 m.

Alum shale is a common problem to foundations of buildings, but tunnels and caverns are also known to require comprehensive rehabilitation works due to alum shale.

Chemically instable minerals

Some iron sulphides, in particular pyrrhotite are known as chemically instable, and will produce sulphuric acid as a weathering product.

Anhydrite is a calcium sulphate mineral which readily alters to gypsym. Gypsum has a larger volume than anhydrite, and thereby a swelling pressure will be a result of the process. This may eventually cause disintegration of the rock, and also severe strains to support constructions. Anhydrite is a serious problem to many underground constructions and may cause extensive maintenance and rehabilitation demands.

Water leakage

Water leakage is an important factor regarding operation and maintenance of underground constructions, but also the environmental problems related to the groundwater lowering may be very serious.

Water ingress to underground constructions may be merely an aesthetic problem. In particular, water in combination with frost can be a challenge in traffic tunnels, and a main reason for high operation and maintenance costs. A moist environment is often a problem for electronic instruments and fine mechanical installations imposing high maintenance costs.

It is therefore utmost important to "handle water" both through proper design and cautious construction work.

11. ROCK SUPPORT METHODS IN NORWEGIAN TUNNELS AND CAVERNS

Eystein Grimstad

INSPECTION AND ANALYSIS OF THE MAINTENANCE PROBLEMS

In the oldest tunnels or underground openings in good rock mass quality without water leakages, mapping of the rock and support design may be carried out because of easy access. In many old tunnels inspection may be difficult without removing water and frost protection panels or polyethylene foam covered with sprayed concrete for fire protection. Many of the old tunnels have to be widened both in width and in height in order to fulfil the new standards. In these cases all panels and most of the rock support has to be removed. For all cases it is important to study and evaluate all documentation from the preinvestigation and particularly data form the construction period. If the documentation concerning the geological data and rock support is detailed and of good quality, the inspection may be concentrated on particular areas of the tunnel, where problems may be expected. This may save a lot of time and resources during the inspection, and make it easier to design new support.

The amount of rock support has increased substantially and the types of rock support have changed during the last 50 years in all tunnels and underground openings. Particularly the use of wet mix fibre reinforced sprayed concrete has changed the philosophy and the practical work with rock support. Because of this the need for upgrading and improvement will vary a lot depending on the age of the tunnel or underground opening. The level of safety and the expected or planned working time of the underground opening are important when the level of rock support is decided.

Headrace tunnels for hydropower was mainly unsupported in the old days, except in very poor rock were cast concrete lining was installed. Downfall of single blocks is normally accepted in headrace tunnels as long as they do not reduce the water flow to the power plant. When a headrace tunnel or water supply tunnel is in service inspection is difficult or impossible due to poor access. However, sometimes large cave-ins can block the water flow and make it necessary to empty the tunnel and carry out repair work. This gives loss of income for the owner of the power plant. In this case sprayed concrete combined with grouted rock bolts and reinforced ribs of sprayed concrete or cast concrete lining is installed in order to avoid future collapses.

MAINTENANCE OF RAILWAY AND ROAD TUNNELS WITH HEAVY OR LOW TRAFFIC.

Some railway and road tunnels have to be in service during maintenance or upgrading. This increases the time and cost for the work. In some cases it will be better to construct an additional tunnel parallel to the old one if it is a single tube tunnel, which has to carry heavy traffic. In other cases the traffic is let through in certain time intervals making the work difficult and expensive. In cases of twin tube tunnels one tube may be repaired while traffic has to go on in the other tube. Irrespective if the tunnels are widened or not, rock bolts and sprayed concrete is the main type of rock support for such repair work. Cast concrete lining is impossible to carry out in short time intervals, because of the installation of formwork and the curing time for the concrete is too long. In tunnels where water and frost protection is placed directly on the rock surface continuous inspection of the tunnel is impossible without removing the lining. In these cases documentation from the construction period is essential for designing new or additional support.

Underground caverns. In case of vulnerable installations in a cavern like water treatment plants or hydropower stations, repair has to be carries out very carefully with protection of the installations during the work. Because of the installations the access to the periphery of the caverns is often limited. Scaling of loose rock or concrete slabs is normally out of question in such cases. In stead of scaling, mesh may be installed, fixed to rock bolts or combined with sprayed concrete in order to avoid falling rock. Spraying of concrete is also difficult because of dust and rebound from the spraying may destroy installations. In this case all installations have to be covered or temporary removed before spraying.

From waste water treatment plant near Oslo with limited access for repair or improvement of rock support.

SUPPORT IN HIGH STRESS REGIMES OR SQUEEZING ROCK WHICH STILL IS DEFORMING AFTER LONG TIME.

In some cases when an underground opening or tunnel is constructed in extremely high stress or squeezing rock, small but long-term deformations may gradually cause cracking of cast concrete or sprayed concrete lining. Also rock bolts may be deformed and thus loose some of its corrosion protection. In some cases movements have been observed more than ten years after construction. Only in cases when heavy and more rigid support has been installed long time (1-3 years) after excavation which is combined with flexible temporary support, long term deformations may be avoided.

REPAIR OR IMPROVEMENT FOR A NEW FUNCTION

Dependant of the age or condition of a tunnel or underground opening a decision has to be taken whether only a maintenance or repair at the same level or quality, or an upgrading to a higher level should be carried out.
Normally the requirements for safety and comfort are increasing with time. This makes it necessary to upgrade tunnels and underground opening from time to time. In this case widening and /or additional rock support has to be carried out. The type of support may depend on the designed working life of the construction.

In some cases when damage is observed on the construction, or after small dawn fall of rock in old unlined tunnels, only local repair is normally carried out. The repair may be of temporary character, or may be done for a long operation time. This depends often on availability of money or general planning for the future of the construction.

12. DETERIORATION MECHANISMS AND DURABILITY OF SPRAYED CONCRETE IN NORWEGIAN TUNNELS

Per Hagelia

ABSTRACT

Modern steel fibre reinforced concrete used for rock support in Norwegian tunnels showed chemical deterioration phenomena related to water leakages. Ground waters enriched in sulfate and bicarbonate had caused Thaumasite Sulfate Attack (TSA), detrimental internal carbonation and local acid attack. Concretes subjected to ion poor ground waters were usually sound, although sometimes affected by detrimental internal carbonation or Ca-leaching. Alkali silica reaction was unimportant.

A novel deterioration process was discovered in subsea tunnels within sprayed concrete covered by layered Mn-Fe biofilms. Bio-chemical reactions within the biofilms had caused acidification of the saline waters. Acid resistance of sprayed concrete decreased with time due to simultaneous progressive development of internal carbonation, Ca-leaching, TSA, chloride and magnesium attack. This process was very aggressive and had sometimes caused deep or complete disintegrations after < 5 years.

The most severe attacks involved loss of bearing capacity due to cement paste degradation, steel fibre corrosion involving thinning and strength loss of the remaining sound sprayed concrete. Depassivation of steel fibres was due to chlorides, acids, carbonation and bacterial action. Life time of significantly influenced sprayed concretes is less than the design life of 50 years. Yet where rock mass rating had been applied for design the concrete linings were much more durable. An assessment of residual life time is in each case critically dependent on rock mass conditions, spray thickness, hydraulic gradient and ground water chemistry. Consequences for further deterioration, maintenance and timing of repair are discussed.

Keywords: Ground water chemistry, concrete deterioration mechanisms, Fe-Mn biofilms, steel fibre corrosion, durability.

INTRODUCTION

Recently an accredited publication from the International Tunnelling Association (ITA) Working Group No 12 “Shotcrete Use” summarised ten years of work on the durability of sprayed concrete (Franzén et al. 2001 [1]). Their work was based on national reports involving a great number of cases, applications, materials and ground conditions. However, the durability evolution of sprayed concrete linings in under ground space turned out to be an extremely complex subject. Generalised key data for a great number of tunnels around the world were summarised, whilst data concerning the effects of time spans of years were seldom available. In most cases the standard quality and material property parameters were available for 28-120 days old sprayed concrete only. Thus a state of the art report on durability of sprayed concrete used for rock support was considered to be a bit premature and is still missing (cf. [1]). The Working Group 12 focused much on strategies for future work and recommended the use of four main durability aspects pertaining to data collection:

1) Complete information about the exposure situation (i.e. chemical- and mechanical loads. based on ground water chemistry and rock mass characterisation, respectively).

2) All necessary sprayed concrete material information to be able to quantify exposure resistance parameters (documentation of the mixes used, spray thicknesses, presence of structural inhomogeneities etc.).

3) Duration of exposures, if necessary, split on the local set of processes (time elapsed since a defined diagnosed deterioration process has influenced the spray, involving mechanical loads and deformations, freeze/thaw cycles, vibrations, impacts and abrasive action, chemical attack from ground water and other liquids along with aggressive components in the atmosphere).

4) Design basis and lifetime expectancy compared to specifications and work execution (the balance between requirement and design, f. ex. permanent linings require more than preliminary).

The designed life time for Norwegian tunnels is 50 years and therefore the life time expectancy of permanent rock support including sprayed concrete and rock bolts is the same. In Norway the design is frequently based on numerical rock mass rating using the Q-system (e.g. Barton et al. [2] and later updates), although exceptions are numerous. The main purpose of rock classification is in any case to provide a long lasting safety for the tunnel traffic. Fallouts of sprayed concrete and rock should be avoided. Another concern is how to estimate the life time for sprayed concretes subjected to different environmental loads (exposure situations), since secondary weakening may represent a potential safety problem involving unforeseen maintenance costs and risks.

NORWEGIAN EXPERIENCE, GUIDANCE AND ENVIRONMENTAL CLASSIFICATION

Norway has a very long experience with planning, construction and maintenance of tunnels within a huge variety of environments and for different purposes. The main guidance for proper use of sprayed concrete for rock support is represented by Publication 7 from the Norwegian Concrete Association [3]. This document recommends that the design of sprayed concrete linings (spray thickness etc) should be based on the Q-system, and includes the essentials of concrete mix design with reference to standards. All sprayed concrete should be made with silica fume (SF) or another pozzolanic material using the wet method. Steel fibre reinforcement is most commonly employed. Sprayed concrete for permanent rock support is specified within the Durability Classes M60-M40 with compressive strengths ranging from B25-B45 (cf. NS-EN 206-1[4]). Publication 7 also makes use of Strength Class B40 thus deviating from NS-EN standards. In most cases of aggressive grounds B45 (45 MPa) has been used in combination with M45-M40 corresponding to water/cement ratios (w/c) 0.45 to 0.40.

According to Publication 7 only carbonation, calcium leaching and fiber corrosion have been identified with certainty, the latter being essentially restricted to the outer few mm of carbonated sprayed concrete. Examples of chloride penetration were also reported. Deteriorations were restricted to leakages, whilst effects of freeze/thaw were unimportant. As yet, experience is too scarce to establish how deterioration will influence the service life and life cycle costs of sprayed concrete. In sub-sea tunnels the saline water leakages were of particular concern, implying special durability requirements for rock support methods. Moreover the potential for Alkali Silica Reaction (ASR) was not resolved. However, no alarming features were reported. The present day Publication 7 was to a great extent based on a national durability study undertaken about 12 years ago (Davik [5, 6]. Iron deposits and "algae" where very commonly observed within the subsea tunnels causing clogging of drains. Concrete deterioration was mostly restricted to thin sprays (< 5 cm). Occurrences of loose debris on concrete surfaces in some tunnels were interpreted to most likely represent rebound from the spraying operation.

Since 2003 NS-EN-206-1, including a National Annex (NA), has been applied in Norway. In contrast to the previous classification system this requires documentation of ground water and soil composition. The National Annex mainly reflects the Norwegian state of the art.

As regards "old" sprayed concrete, useful for a durability study, it should be noted that available concretes mostly were made just after the introduction of a previous fourfold classification scheme (1986-2003); here saline waters and sulfate ground were regarded as "Very aggressive" and "Highly aggressive", respectively. Such conditions sometimes required special efforts including the use of Sulfate Resisting Portland Cement (SRPC) with SF.

OBJECTIVES

Most sprayed concrete in aggressive environments are still young and experience pertaining to durability of modern sprayed concrete is just about to emerge. The present work focused on chemical deteriorations which have not yet been studied in detail earlier. The objectives were to:

1) Present a brief summary of deterioration phenomena in Norwegian sprayed concretes, as based on diagnosis by microscopy and other techniques.

2) Characterise the water chemical environmental loads, with a look also to mechanical effects

3) Put the deterioration phenomena into a relevant hydrogeological context, and

4) Discuss the implications for remediation, further deterioration, maintenance and repair.

With a few exceptions the present work was based on modern wet sprayed concrete used for rock support in tunnels.

SELECTION OF SITES, WORK STRATEGY AND SUMMARY OF METHODS

Selection criteria

The investigated structures were selected on the basis of the following criteria: a) They should include typical ground conditions involving (hydro-) geological variation and ground water compositions, b) Deterioration characteristics should be representative and relevant for structural performance, c) Investigations should mainly focus on the most common and modern mixes, d) The age of structures should be variable, and e) Basic documentation should be available. Most of these criteria comply with the recommendations from the ITA.

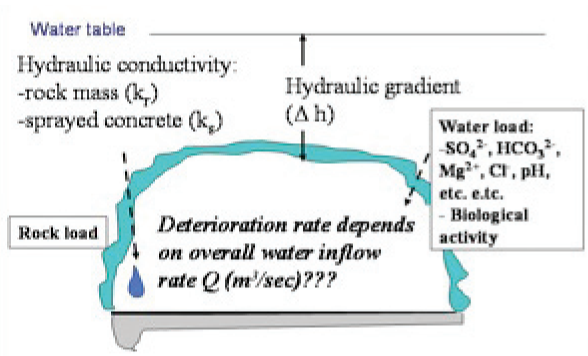


Figure 1: Principal aspects of environmental loads acting on sprayed concrete in tunnels.

HYPOTHESES AND WORK STRATEGY

Figure 1 gives an illustration of the principal environmental loads which act on sprayed concrete used for rock support. With this in mind it was hypothesised that chemical deterioration mechanisms are not solely dependent on the water composition but perhaps also on the "driving force" represented by the hydraulic gradient. Moreover it would seem relevant to investigate to which extent deterioration rates depend on the volumetric flow rate: It seems likely that also volumetrically small leakages, spread over large concrete outer surfaces may cause significant degradation under certain circumstances. The effects of evaporation due to tunnel draft should indeed lead to increased concentrations of aggressive ions, and this process should be most efficient in rather thin water films. Contrary to this, waters acting from behind the spray should represent more pristine ground water compositions. Adhesion (the quality of the concrete rock interface) may be influenced by water pressure, paste transformation or weak precipitates from ground water, in addition to the rock surface roughness and quality of the work. In general it must be expected that spraying directly against a quite leaky rock mass will lead to a somewhat lower quality than concrete on dryer faces, yet depending on the local volumetric flow rate: Moist surfaces or small leakages may not have influenced the initial properties of thick sprays.

WATER CATEGORIES AND CONCRETE SAMPLING WITH COMMENTS TO ROCK MASS RATING DATA

Water samples were collected from fast crack bound water (representing quite undisturbed ground waters) as well as from waters interacting with concrete surfaces AND from metal water panels. It was expected that effects of evaporation should be easiest to detect in waters draining from water panels as opposed to leakages in direct contact with concrete, which are likely to absorb the aggressive ions instead. Water analytical data were arranged according to the Environmental Classes pertaining to chemical attack (NS-EN- 206-1). Core samples of sound to variably degraded concrete were extracted and concrete surface debris samples were also included. Most concrete samples corresponded directly to a particular water quality.

Systematic documentation of rock mass parameters (Q-values) was only available from two of the investigated tunnels whilst general geological data were available.

MATERIALS AND METHODS

The cases and materials studied represent "real world" sprayed concrete used for rock support, most of which were modern concretes with a high initial quality. This work represents the first systematic petrographical study of sprayed concretes in Norwegian tunnels within a water chemical context. About 100 cores (Φ = 50, 70 or 100 mm) were extracted from ten different structures (cf. Table 1) along with several big spalls and small debris samples. More than 200 thin sections were prepared from concrete cores and spalls and investigated under a standard polarising microscope in the Technology Department at NPRA. Surface debris including microbes and other loose and potentially water soluble materials from within degraded zones in the cores were analysed by X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) at the Museum of Natural History, Oslo. Compressive strength was determined for a few cores at Sentrallaboratoriet (NPRA) and NIVA Oslo analysed the waters and some microbes. A detailed documentation of samples, analytical techniques and results will be reported by the present author in a doctorate thesis later this year.

RESULTS AND DISCUSSION

Anatomy of chemical attack and consequences for sprayed concrete thickness

Deterioration may lead to 1) Fallout of strong thick concrete slabs (sometimes involving the rock material behind or 2) Focused or widespread weakening, thinning and spalling. The first case was facilitated by early cracking across the sprayed concrete slab in at least two directions, combined with absence or later weakening of adhesion. Cracking was mostly due to readjustments in the rock mass. Aggressive waters easily attacked the steel fibre reinforcement on cracks and contributed to transformations along the adhesion zone. Experience from the Oslofjord subsea tunnel and other places have demonstrated that fallout might take place at an early age. The second case involved bulk diffusion of aggressive waters from the back side of the concrete slab with water penetration along minor cracks, leading to concrete-water interactions also from the outer concrete surfaces on the tunnel facing side.

Figure 2 illustrates the general anatomy of chemical attack (Hagelia et al. [7]). Concrete within Layer A at the interface and Layer C of the outer surface region may be transformed, depending on the nature and extent of the attack, whilst Layer B represents more sound concrete. Aggressive ions attack from both sides and eventually lead to a complete breakdown of the bearing capacity of the concrete as Layer B is diminishing. Spalling (S) and calcite stalactites may develop during the course of this process. A very similar lay-out has been reported by Romer [8] from sprayed concrete tunnel linings in Switzerland. Sprayed concrete in tunnel space as well as in open air tend to accumulate particles and sometimes biological material on the rough outer surfaces. This again attracts moisture which might facilitate chemical reaction or growth of for example bacteria. Exhaust fumes may also take part in the reactions but these effects were not studied.

CONCRETE DEGRADATION PHENOMENA STUDIED WITHIN THREE WATER CATEGORIES

A summary of the investigated structures and material properties of sprayed concretes is given in Table 1. Material properties are mostly given by a reported range as based on previous work, representing most of the real variation. The structures are represented by subsea tunnels as well as land tunnels within different geological environments. Several of the sprayed concretes were investigated around 1996 within the previous durability project. Table 2 gives a summary of the overall water chemical compositions at each site. An outline of the main durability problems, maintenance work and sprayed concrete thicknesses for each case are presented in Table 3. The accumulated data are based on the investigation of the present author as well as Davik [5], Hagelia et al. [7, 9], and other available documents [10].

The exposure conditions comprised 1) freshwaters in land tunnels and land sections of subsea tunnels; 2) sulfate enriched ground sulfide derived from Oslo Alum Shales, and 3) saline ground waters within subsea tunnel sections. Concretes were studied within these three water categories as shown in Table 2. Mostly several deterioration mechanisms were acting together and their impact varied from being rather insignificant to having important structural effects.

The chemical Exposure Classes of NS-EN 206-1 were applied. It was however also possible to address the impact from chlorine and carbonation, as has been done in a several cases below. Although there may be some uncertainties as regards the initial quality of sprayed concrete at a detailed level, there seems to be no reason to infer that the observed deterioration phenomena reported herein were caused by low quality and poor workmanship. Instead in many cases deteriorations had indeed influenced well documented high quality concrete.

Surface dry sprayed concrete was usually found to be in a good shape showing up to a few mm of surface carbonation without any other obvious secondary

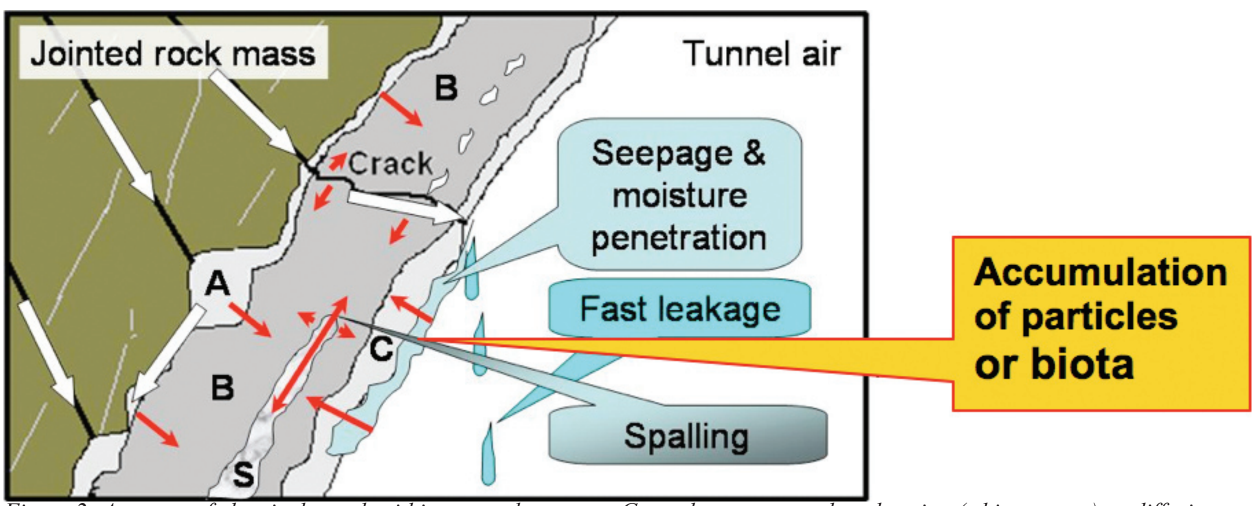


Figure 2: Anatomy of chemical attack within sprayed concrete. Ground water enters by advection (white arrows) or diffusion (small arrows). Layers A, B, C & S are explained in text.

Locality (year of concrete placement)	Type of structure	Concrete age at time of sampling (years)	Rock conditions	Cement type & w/c ratio	Additives (% by cement weight) & accelerator	Cement contents (equiv. in kg/m3) / Designed strength (real range, cube)	Reinforcement. Fibres in kg/m3: Designed/real range
Lier *) *Dry* SE Norway (1965-1971)	Railroad tunnel	Ca 25*), Ca 35	Granite, dolerite Extensive rock burst Fractures with clay	PC (not specified) 0.4-0.6)	HS-3 (2.5-5 %) (= portlandite + C3A + PC-rapid)	Ca 500/B50-B60	Steel grid & none
Harpefoss E Norway (1984)	Access tunnel to hydropower plant	13, 16	Metasediments with black gneiss	PC (MP30?) Ca. 0.4-0.5	Possibly Fly ash & water glass	No documentation	None
Åkeberg Oslo (1970 & 1987) **)	Road cut in city centre	13 (30**)	Alum Shale, syenite	SRPC 0.45-0.50	SF & water glass (** no SF)	Ca 500 / Ca B45	Steel fibre (**steel grid)
Ekeberg Oslo (1992)	Urban highway tunnel	8	Alum Shale, clay stone	SRPC 0.45	SF (8 %) & water glass	Ca 530/Ca B45	Steel fibre
Svartdal Oslo (1998)	Urban highway tunnel	2, 8	Alum Shale	SRPC 0.39	SF (5 %) Al-sulfate	530/B40	Steel fibre
Oslo city *Dry* (about 1970)	Abandon civil defence shelter	Ca. 30	Alum Shale (swelling)	SRPC Ca. 0.5-0.6 **)	No documentation	No documentation	None
Freifjord *) NW Norway (1990-1991)	Subsea road tunnel (highway)	5*), 9, 13, 16	Gneisses, local marble Joints including chlorite etc	PC-rapid 0.38-0.47	SF (6-8 %) & water glass	560-580 /B45 (30-58 MPa)	Steel fibre 50-70/26-44
Flekkerøy *) S Norway (1988)	Subsea road tunnel	8*), 13, 15	Gneiss, amphibolite, Joints with illite and other clay	PC-rapid 0.45-0.47	SF (14 %) & water glass	550 /B45 (27-41)	Steel fibre 45/36-56
Byfjord *) SW Norway (1990-1991)	Subsea road tunnel (highway)	14	Phyllite, schist, gneiss Joints with chlorite etc	PC rapid 0.41-0.46	SF (1 %) & water glass	485 /B45 (30-36 MPa)	Steel fibre 55/30-52
Oslofjord SE Norway (1998)	Subsea road tunnel (highway)	5, 6, 7	Granitic gneiss, pegmatite, amphibolite Joints and fractures with montmorillonite, kaolinite & illite	PC-standard PC-rapid 0.41	SF (5 %) & Al-sulfate	540 /B40 (54-66 MPa)	Steel fibre 45/36-49

*Table 1 Summary of investigated structures and material properties. Tunnels marked with *) were also included in a previous study (cf. Davik [5]). PC = Portland cement, PC-standard = Norcem Standard Cement, PC-rapid = Norcem RP 38, SRPC = Norcem Sulfate Resisting Portland Cement; SF = Silica fume (SF). Wet method except for "Dry" = dry method). Åkeberg road cut **) includes an older SRPC based sprayed concrete from 1970 without SF with w/c ratio about 0.5 and steel grid instead of steel fibres. The Harpefoss aggregate was marginally susceptible to Alkali silica reaction otherwise aggregates were innocuous.*

Locality (n)	pH	Cl^- mg/L	NH_4^+ µg/L	NO_3^- µg/L	SO_4^{2-} mg/L	HCO_3^- mg/L	Na^+ mg/L	K^+ mg/L	Mg^{2+} mg/L	Ca^{2+} mg/L	Exposure classes: NS-EN-206-1
Lier (1)	8.18	2.8	< 5	< 1	22.3	173	15.0	0.79	12.1	44.5	X0 (XA1?)
Harpefoss (4)	5.7-6.1	12.2-16.9	n.a.	< 1.	102-111	n.a.	3.2-11	0-7.8	1.5-3.9	38.5-59.9	X0 (XA1?)
Freifjord, *f* (2)	7.0-9.16	24-26	n.a.	n.a.	124-146	n.a.	168	5.8	0.89-1.0	2.54-13.3	X0
Byfjord, *f* (1)	8.33	260	< 5	465	51.2	141	193	14.3	15.4	14.6	X0
Oslo, *f* (3)	7.43-8.16	9.4-123	<5-41	55-570	13.3-21.1	64 -165	12.8-76.3	1.6-3	2.98-5.57	20.7-39.6	X0
Åkeberg (1)	7.6	29	n.a	25000	1841	274	26	22	110	615	XSA
Ekeberg (2)	7.0 (4-5)	10	n.a	14000-18000	592-2031	56 -100	25-43	16-22	20-74	106-574	XSA
Svartdal (1)	6.84	18.7	100	300	541	67	44.4	9.09	21.4	172	XSA
Freifjord, *s* (12)	5.5-7.33	5110-19900	<5-96	81-1335	410-2710	23 -101	1680-8550	11-36.9	158-1310	1340-4040	XA1-XA3 (XSA?)
Flekkerøy, *s* (7)	7.12-8.07	11100-27900	<5-8100	56-47000	1380-2600	43 -146	5080-12800	136-369	745-1420	429-3100	XA2-XA3 (XSA?)
Byfjord, *s* (6)	7.50-8.15	1000-50200	119-7400	290-52000	50-3830	41-151	5720-27800	50.7-507	998-3280	562-1660	XA2-XA3 (XSA?)
Oslo, *s* (10)	6.64-7.83	16900-19300	6-1710	5-1535	2550-2740	132 -161	8640-9300	160-348	1180-1340	394-1360	XA3 (XSA?)
Seawater Oslofjord (1)	7.74	18600	< 5	146	2630	144	10800	390	1370	413	(XA3)

Table 2: Tunnel water chemistry given as range within each category, excluding ditchwater. n = number of water samples at each locality; n.a. = not analysed. Subsea tunnel sections in freshwater and saline water are denoted "f" and "s", respectively. The seawater sample was collected from 60 m depth at NIVA Solbergstrand, Oslofjord. Bicarbonate contents calculated from alkalinity. Data from this study except: Harpefoss, Åkeberg and Ekeberg (Hagelia et al. [9]) and a few samples from Freifjord, Flekkerøy and Byfjord (Davik [5]). Exposure classes for concrete influenced by water; See text for details and discussion.

transformations of the cement paste matrix. However it is important to realise that where draw-down of the water table has occurred at some stage, a dry concrete surface might still hide weaknesses caused by previous water attack. This problem is briefly discussed below. Moreover internal deteriorations related to components in the concrete aggregate were also considered (cf. Alkali silicate reactions below). In general, however, almost all of the sprayed concretes were made with a high quality aggregate without aggressive or reactive components.

SPRAYED CONCRETE IN FRESHWATER ENVIRONMENTS

Exposure conditions

The water compositions (Table 2) in the investigated cases classify mainly as non aggressive.

Locality & age of concrete	Practical problem related to concrete	Type and extent of deterioration	Maintenance work up to now	Spray thickness
Lier, E Norway (1965-1973) *Dry method: old technology*	Extensive spalling and falloff. Expensive long term maintenance	Early age sulfate attack & extensive carbonation (also internal)	Removal of weak concrete twice in a year	2 – 25 cm
Harpefoss, E Norway (1984)	No big problem	Minor TSA & PCD apparently slow. *)	Nothing done	2 – 12 cm
Åkeberg road cut, Oslo (1970 & 1987)	Local spalling and deformations started at age <13 yrs	TSA & PCD at age < 13 yrs	Previous 1970 spray replaced in 1987	6 – 18 cm
Ekeberg, Oslo (1992)	Some weakened concrete observed	TSA and PCD at age < 8 yrs	Nothing done	3 – 10 cm
Svartdal, Oslo (1998)	Not yet problematic	Some TSA and PCD at age < 2 yrs	Nothing done	5 – 11 cm
Oslo, civil defence shelter (ca. 1970) *Dry method: old technology*	Abandon mainly due to ground conditions, locally severe spalling and -cement paste crumbling	TSA, PCD, Ettr. Shale swelling probably due to gypsum	Several times in past years	5 – 12 cm
Freifjord, NW Norway (1990-1991)	Cement paste crumbling started at age < 5 yrs	Complex seawater attack: very widespread in undersea section *)	Occasional new spray recently	6.5 – 14 cm
Flekkerøy, S Norway (1988)	Some cement paste crumbling started at age < 5 yrs	Complex seawater attack: locally extensive in subsea section	Occasional new spray recently	4 – 15 cm
Byfjord, SW Norway (1990-1991)	Very limited cement paste crumbling	Complex seawater attack: minor effect	Nothing done	2 – 17 cm
Oslofjord, SE Norway (1998)	1) Local rock fall on the road; < 5 years of service: 10 weeks closed 2) Cement paste crumbling started at age < 5 yrs	1) Early age cracking combined with rock load 2) Complex seawater attack: common in subsea section	Repair & extensive replacement locally at age ca 5 years Also due locally to saline ground water	5 – 18 cm

*Table 3. An outline of the main durability status. It should be noticed that cement paste degradation was most typically developed within subsea tunnels, involving thinning and loss of bearing capacity. *) = Minor signs of ASR. See text for further explanation.*

Deterioration mechanisms and examples

The concretes subjected to freshwater loads were essentially intact although some Ca leaching and calcite stalactite formation occurred, which in the general case has no impact on structural performance. This is indeed the most typical observation.

It should be noticed that the presence of bicarbonate dissolved in ground water may enter into concrete and cause some degree of leaching and internal carbonation. There is also some concern about the effects of slightly elevated sulfate contents (< 200 mg/L, i.e. lower than in Exposure Class XA1) because sulfates such as ettringite and thaumasite do not require a very high concentration to form (cf. [11] and references therein).

Locally, however, sulfate attack also was found both at the Harpefoss and the Lier tunnel despite sulfate concentrations < 150 mg/L in these ground waters. At Harpefoss thaumasite had formed locally at the concrete/rock interface in quite modern wet sprayed concrete less than 16 years old [9]. The Lier tunnel [10] was characterised by severe rock burst problems during construction about 40 years ago, and an early stage sulfate attack. This attack was obviously due to significant early water leakages into the tunnel since intergrowth of thaumasite and ettringite as well as large portlandite- and hydrated calcium silicate crystals were found in the large air voids. Presently the concrete is essentially dry, extensively laminated and carbonated. This sulfate attack was obviously due to high concrete permeability and porosity, which also made way for very extensive deep carbonation and severe spalling which is still continuing.

Although the concrete in question represents an expensive maintenance problem for the owner (Table 3) this old dry-spray is not at all representative for the performance of modern wet sprayed concrete mixes. The main lesson to be learned is that ground water loads are not constant and that even the aggressive ion concentrations may change with time.

SPRAYED CONCRETE IN THE ALUM SHALE ENVIRONMENT

Exposure conditions

The exposure conditions were similar to the ones reported by the previous Alum Shale Committee (cf. Bastiansen et al. [12] and Fiskaa et al. [13]) being characterised by very high sulfate concentrations (2000-5000 mg/L) and pH varying from < 2 to 6-7. As such the Alum Shale environment sometimes involves characteristics of Acid Rock Drainage (ARD). In NS-EN 206-1 these conditions are represented by the Exposure Class XSA which has been introduced nationally, among others, due to the well known sulfate attack related to Oslo Alum Shale.

Deterioration mechanisms and examples

The Alum Shale Committee reported on a severe form of sulfate attack causing rapid degradation of the cement paste matrix and severe corrosion of steel. This was attributed to a sulfuric acid attack and ettringite formation induced by the high ground water sulfate concentrations which are derived from sulfide oxidation. However, Hagelia and Grønhaug [14] found that this was instead due to the Thaumasite Sulfate Attack, the effect of which has been detailed in a series of recent papers from NPRA and BRE UK [7, 9, and 11]: The main feature of the attack is formation of thaumasite in air voids and cracks (called Thaumasite formation; TF) and detrimental Thaumasite Sulfate Attack (TSA) at the expense of the cement paste matrix. Thaumasite also contains carbonate, and entrance of bicarbonate from ground water and simultaneous formation of large calcite grains leading to internal detrimental carbonations (referred to as Popcorn Calcite Deposition, PCD). The overall process has been termed TF-TSA-Carbonation (e.g. [7, 9]) and has caused variable effects of structural weakening. It is significant that thaumasite also forms in Sulfate Resisting Portland Cement (SRPC) with silica fume (SF) (see Tables 1 and 3). TSA is well known from the UK and takes place in a moist and cool environment such as in tunnels (cf. DETR [15] and Crammond [16]).
In present day concretes based on SRPC with silica fume (Table 2) the effects of TSA are quite small in comparison with the classic problem in Oslo some 50-70 years ago. As a matter of fact the Alum Shale Committee was first to discover the beneficial effects of SF! Spalling and deformations have still been recorded in modern steel fibre reinforced wet sprayed concrete about 13 years old (e.g. the Åkebergveien road cut, see Table 3). Hagelia et al [9] reported that the effect of the attack depended on the spray thickness, and that if acids were present there is a potential for of sprayed concretes breakdown (6-10 cm thick) within less than 20 years. Although very young (< 2 years) TF-TSA-Carbonation was found in the Svartdal tunnel ([7, 9], later sampling at concrete age 8 years indicated that the process has halted here (P. Hagelia in prep).
Recently the leaching mechanisms related to Alum Shale were studied in detail. The results, including stable isotope analysis, suggested that the source of sulfate involved sulfide oxidation assisted by Acidothiobacillus sp. as well as anhydrite/gypsum dissolution (Hagelia [17].

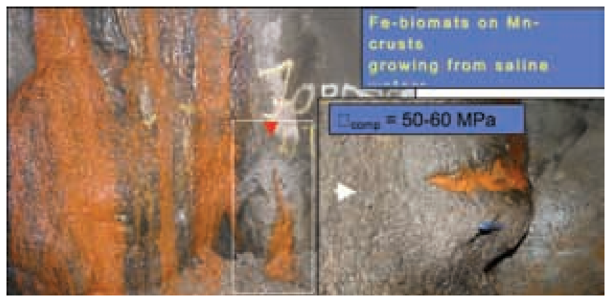


Figure 3: Complex seawater attack in the Oslofjord subsea tunnel facilitated by mild acid attack due to chemical reactions within two layer biomats consisting of Gallionella ferruginea and Leptothrix sp. The process also attacks initially strong concrete from the outer surface (inset).

SPRAYED CONCRETE IN SALINE GROUND WATER

Exposure conditions involving occurrences of hypersaline waters

Sprayed concretes subjected to the saline ground waters within the subsea tunnel sections have up to now been regarded as similar to seawater conditions and compared to seawater attack in bridge foundations. Thus the Exposure Class XA3 or similar has been applied. Yet in NB Publication 7 it is also obvious that the subsea tunnel environment is of special concern and that SF and low w/c ratios are specified. However the present results imply that this should be reconsidered, since significant effects of evaporation has been found in waters draining from Al water panels both in the Flekkerøy- and Byfjord subsea tunnels. Here some waters had become hypersaline: chloride- magnesium- and sometimes sulfate concentrations greatly exceeded those of ordinary seawater (Table 2). The hypersaline waters were typically encountered in relatively slow leakages from water panels in immediate vicinity of fast and busy tunnel fans. It was obvious that draft from the fans had caused this evaporation and that such extremely aggressive waters therefore also must have influenced the near by sprayed concretes.

Hypersaline waters were not encountered within small leakages running over sprayed concrete surfaces. Instead SEM investigations showed that these concretes were consistently influenced by a seawater-like attack, involving elevated Cl, Na, Mg and sulfate in the paste (P. Hagelia in prep). Evidently the sprayed concretes had absorbed these aggressive ions. Small leakages in direct and permanent interaction with saline ground waters had unusually high Ca contents (ca 1000 to 3000 mg/L) in contrast to background and seawater at some 400 mg/L. Ca concentrations also increased downstream on a severely deteriorated concrete surface in the Oslofjord tunnel (Figure 3), implying breakdown of the cement paste matrix (Hagelia [18]).

Deterioration mechanisms and examples

A novel concrete deterioration process was discovered in the subsea tunnels ([18], Hagelia in prep.). Steel fibre reinforced concrete used for rock support was attacked by saline ground waters along the concrete/rock interfaces as well as at the outer very rough and reactive concrete surfaces. The process had frequently led to total disintegration of the cement paste matrix and steel fibres after < 5 years (< 0.5 to 10 mm/year) and was closely related to growth of Mn and Fe biofilms. The typical feature was a bacterially derived black Mn-oxide concrete surface deposit covered by a rusty slime consisting of iron bacteria and Fe-hydroxide (Figure 3).

The reaction mechanisms comprised two principal aspects: 1) redox reactions with production of mild acids with pH about 5.5 to 6.5 and 2) a through solution process leading to secondary mineral transformations. Both processes had caused breakdown of portlandite and Calcium Silicate Hydrate (CSH) in the cement paste matrix, and depassivation of steel. The redox regime was strongly influenced by bacterial activity. Initial oxidation of ground water Mn2+ by Leptothrix discophora (?) led to formation of Na-buserite in pristine dark slime around leakage entrance points through concrete. Buserite quickly transformed into todorokite and birnessite, forming solid black Mn (IV)-rich crusts downstream. Gallionella ferruginea and sometimes Leptothrix ochracae accumulated outside. These bacteria catalysed oxidation of steel fibres and Fe2+ from the ground water, forming ferric compounds such as amorphous ferrihydrite. Also Mn-bacteria, chloride and concrete carbonation assisted in corrosion. Acid production was apparently mostly related to redox reactions between partly oxidised iron compounds and Mn (IV) crust material as was suggested by micro structural relationships, occurrence of Mn crust material with very low O/Mn ratios and preliminary Mn-L-edge spectra. Internally, portlandite and CSH had partially broken down through leaching and Ca depletion, bi-carbonation, Mg substitution, brucite (Mg (OH)2) formation and thaumasite sulfate attack. Precipitates of Mg-calcite and aragonite were predominating over calcite on outer and inner surfaces. Most of these minerals are soluble in weak acids.

At an advanced stage gypsum had formed extensively at the expense of cement paste, building up deposits on the outer concrete surfaces. Growth and accumulation of biomats led to reducing conditions and sulfide formation. Stable S-isotopes suggested gypsum sulfate (δ 34S ≈ 13-25 ‰) was derived both from slightly reduced seawater and oxidised H2S formed through temporary reduction of seawater sulfate underneath dying biota. Crystalline large fibrous carbon with δ 13C ≈ -25 to -26 ‰ being incorporated within gypsum also pinpoints the link to the bacterial processes. The combined effects of biotic activity and abiotic secondary mineral transformations resulted in microcracking due to both positive and negative volume changes. Constant replenishment of saline Mn and Fe enriched waters facilitated continuous formation of layered Mn and Fe biofilms and a sustained acid attack, being increasingly effective as microcracking continued to develop. The process also attacked high quality concrete (50-60 MPa; Figure 3).

It is obvious that the so called "algae" reported from several subsea tunnels in previous investigations in fact represent iron and manganese bacteria. Their negative effects were in fact noticed by Hansen [19] already many year ago, who stated that especially the "black deposits" (e.g. manganese deposits) were most harsh to the sprayed concretes.

The effects of this attack is summarised in Table 3 for each subsea tunnel (cf. "complex seawater attack"). The impact of this composite deterioration mechanism had apparently increased with age at several locations. It is important that gypsum layers appeared to accumulate with age; in fact within the Freifjord tunnel a wet mush like greyish gypsum rich slime has been build up within large areas in the deepest part of the tunnel. This implies that the acid attack has moved into the adhesion zone as was also seen in thin section. Also cast concrete in this tunnel was affected. This type of deposit was by some investigators thought to represent rebound, whilst XRD analyses have shown then to consist of mainly gypsum and occasionally also thaumasite.

The Oslofjord and the Flekkerøy tunnels were also typically influenced by the "complex seawater attack", whilst this effects were quite minor in the Byfjord tunnel. It seems likely that this reflects a more relevant spray thickness as well as more optimal leakage conditions.

As regards dry or fairly dry concretes the durability was apparently quite normal in the subsea tunnels, without any obvious alarming features. Yet localised calcite stalactites (sometimes with internal brucite deposits) or other leaching phenomena occurred.

STEEL FIBRE CORROSION DUE TO CHLORIDES, CARBONATION AND BACTERIAL ATTACK

It was established above that steel fibres were severely attacked in connection with Fe and Mn deposits and bacteria. The steel fibres were attacked by several mechanisms which at places led to their ultimate destruction. Obviously chlorides had a severe effect. But also contact with secondary internal calcite in the form of PCD was important both within the Alum Shale environment and the subsea tunnels. This is due to the infiltration of bicarbonates in ground water which reduced the pore fluid pH to about 8-9.

An interesting "pre-rusting effect" was found within most concretes from subsea tunnels: The steel fibres here had a strong tendency to corrode initially shiny fibres on the core surfaces soon after extraction, even after having been washed in ion poor water. In contrast steel fibres in concrete cores from the freshwater environment always remained uncorroded. Obviously the influence from the saline ground water attack had already contributed to some depassivation of the steel. Investigations by Electron Microprobe Analysis (P. Hagelia in prep) has shown that Cl concentrations in mildly affected CSH may exceed 0.5 wt % of the cement paste yet excluding microcracks and micro pores which frequently contained more concentrated Cl. The phenomenon of prerusting has previously been treated by Novak et al. [20]. Finally steel fibre corrosion was facilitated by fast bacterial iron oxidation (see above) and by manganese oxidising bacteria which are known to cause ennoblement of steel (cf. Dickson et al. [21]).

INSIGNIFICANT TRACES OF ALKALI SILICA REACTION (ASR)

ASR in Norwegian bridges and dams develop very slowly and usually only becomes apparent after several decades. Wigum [22] evaluated the possibility for ASR in sprayed concrete and argued that their typically high cement contents combined with a susceptible aggregate and possible presence of undispersed silica fume could perhaps lead to reaction.

Within the present study two cases of ASR were identified, both of which in fact just represent curiosities. The first was in the Harpefoss tunnel where the aggregate contains about 20-25 % reactive aggregate (rich in microcrystalline quartz [23]). Here ASR gel was developed as a very thin marginal deposit within extremely few air voids in 13 and 16 years old concrete. Although ASR might develop further it is rather unlikely in view of its rarity. The second case was related to ASR gels formed locally at the expense of undispersed silica fume in the Freifjord tunnel. The observation was made in a sample from just five years old concrete. However later inspection 11 years later did not indicate any negative structural effects. Moreover none of the other thin sections from this tunnel indicated ASR, since most of the silica fume was well dispersed. Microscopy of more than 200 thin sections indicated that the silica fume is generally extremely well dispersed, which means that the pozzolanic effect was very effective.

It may be concluded that ASR in modern Norwegian sprayed concretes is unimportant. This contrasts with experience from Iceland where ASR seems to be present in certain environments (Harðarson et al. [24]).

COMPRESSIVE STRENGTH OF SAMPLES FROM SUBSEA TUNNELS

Concrete cores from the Freifjord-, Byfjord- and Oslofjord subsea tunnels were selected for testing of compressive strength (relating to cube) as based on petrographic criteria. Some long cores were cut into two, thus testing the inner and outer layer. All cores were visibly quite sound without any obvious cracks and flaws, whilst petrography had indicated various impacts of magnesium attack with traces of thaumasite and internal carbonation (P. Hagelia in prep). The main conclusion was that scattered internal influence of the saline ground water attack did not seem to have a very strong influence on the compressive strength (yielding about 40-55 MPa), whilst when about 40-70 % of the cement paste matrix had been transformed into MSH with brucite and a little thaumasite the strength had dropped by about 50 % or more (about 25 MPa). There was a tendency that outer layers influenced by saline waters from the tunnel side were weaker than concrete further inside. This was partly due to the magnesium attack which was characterised by extensive shrinkage and microcracking in MSH dominated pastes.

Samples with full scale TSA and magnesium attack were much weaker and could not be tested. It is expected that their compressive strengths were in the order of a few MPa (maximum) with almost no tensile strength. Obviously the still weakest concrete was represented by debris which readily was washed away or had fallen down.

THE GEOLOGICAL CONTEXT

Significance of rock mass rating as regards sprayed concrete durability

Although the Q-system is well embedded in NB Publication 7 the reality is quite often different, ranging from no documentation to a qualitative engineering judgement based on registration of weakness zones, occurrences of clay etc.

The consequence is that we frequently do not know precisely the rock mass condition behind a particular spray, implying that the effect on stability due to deteriorations is difficult to judge about. It is important to realise that the Q-system also accounts for presence of water through the important term Jw (Joint Water Reduction Factor). Thus accordingly the Q-values may be reduced significantly depending on the characteristics of water inflow. The Q-system readily states that a water load should be compensated by a thicker sprayed concrete layer.

Since water flow slows down as a function of the thickness of the traversed medium, it is expected that appropriate application of the Q-system should contribute to an extended durability of the sprayed concrete linings also with respect to water loads. In this respect it is very interesting to note that the degradation rate in the Byfjord tunnel was very insignificant despite the presence of highly aggressive waters here. Also in the Svartdal tunnel, where early stage (< 2 years) thaumasite and internal carbonation was detected, later observations at a concrete age of 8 years suggested the attack has halted or slowed down. It is possibly significant that only in these tunnels a systematic rock mass rating had been undertaken: In fact the final sprayed concrete thicknesses applied here were in both cases complying well with the prediction by the Q-system (Bøyeie [25], Hval [26]). However, changes over time in rock mass hydraulic parameters or ground water chemistry may also lead to an overall less aggressive environment towards concrete in some instances (drawdown of the water table, depletions of aggressive ions along rock joints etc.).

The hydrogeological environment and effect of hydraulic gradient

Deteriorations of all kinds were for all practical purposes restricted to water leakages and the typical situation was a large contact area between concrete and aggressive water. Røhrsveen and Lygre [27] have previously rated surface phenomena including calcite precipitation/stalactite formation and iron deposits in several subsea tunnels using a scale from 0 (no influence) to 5 (most influenced). In view of the detrimental effects related to the iron deposits these data were investigated further: Compilation of data from the Flekkerøy subsea tunnel (averaged pr 50 m in order to minimise scale effects) shows that there is a positive correlation between Ca and Fe deposits and the size of tunnel areas influenced by saline leakages (Figure 4B and C). Previously Hagelia [28, 29] reported that the total leakage area, X (the % of a unit tunnel area influenced by spread and volumetrically small water leakages) obeyed the following preliminary empirical equation: $X = \frac{h - 30.2(h_r/J)^{0.27}}{0.07(h_r/J)}$ where h = hydraulic gradient, hr = rock cover and J is the number of steeply dipping joints/m2 (60o – 90o). J simulates the hydraulic conductivity of the rock mass in a rough sense, and variations could under favourable circumstances also be detected on resistivity profiles (Hagelia [30]). Combined with the data in [28] it could further be substantiated that there is a rough positive correlation between registered Fe + Ca surface deposits and the total leakage area X in eq. (1) (Figure 4A). Even more important, there is a steep positive correlation between the same surface deposits and the hydraulic gradient (depth beneath sea level; Figure 4D).

These results prove that concrete deterioration in the subsea environment depends on the hydro geological lay out; the effects of chemical deterioration are not solely depending on the NS EN-206-1 exposure classes but indeed also on the hydraulic gradient (driving force). Preferably future systems should be incorporating these effects as a better basis for planning, exposure classification, cost analysis and forecasting of maintenance costs.

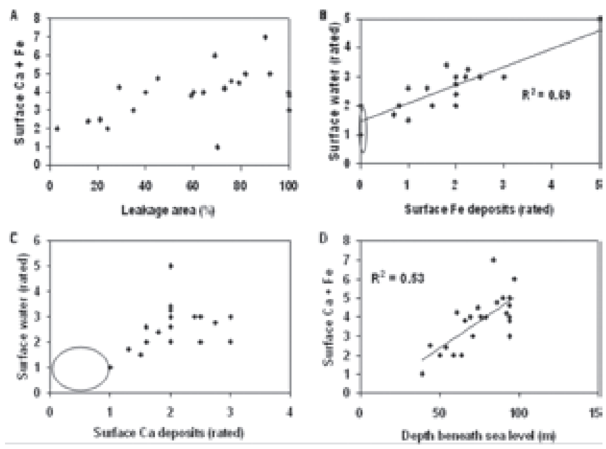


Figure 4: Surface deposits of iron ± manganese (Fe) and Calcite (Ca) show positive correlation with leaching area (A); local surface waters (B, C) and hydraulic gradient (D). Data from the Flekkerøy subsea tunnel. Ellipses represent variation in the fresh water sections under land.

PRACTICAL IMPLICATIONS

Characterisation and classification of exposure conditions

An important finding was that deterioration pattern in sprayed concrete deviated from those found in cast concrete, such as bridges and others. Influence from high hydraulic gradient and/or biofilms frequently has had a profound negative effect within otherwise aggressive environments, implying that environmental loads on sprayed concrete represent to a certain extent a new field of experience.

In general saline ground waters in subsea tunnels have up to now been regarded as the same as seawater. NS-EN 206-1 only considers static water loads and the consequences of mobile water are not well explained. Yet in some countries including the UK the mobile and highly mobile ground waters are accounted for by Exposure classes (cf. Building Research Establishment [31] including references to British Standard). This is due to the experience that the highly mobile waters (defined as slowly moving ground waters such as in tunnels) have a different impact on concrete than static waters. In fact, whilst mildly acidic water usually has no effect when static, a highly mobile water with the same pH (about 5.5 to 6) usually has detrimental effects. The same holds true for aggressive ions which is due to the constant replenishment provided by the running water. Highly mobile waters are not easily allowed to buffer or equilibrate with concrete surfaces and hence build up a protective layer. Protective layers such as outer carbonation and Mg (OH) 2 which are well known from coastal bridges do not easily build up in the same way when concrete is influenced by running aggressive waters driven by a gradient. This is precisely why magnesium deposits and carbonation in the form of PCD can form deeper within sprayed concretes along with thaumasite.

The additional effect from the "driving force" as represented by the hydraulic gradients acting on the sprayed concrete linings makes the situation perhaps even worse. As such the present author would advice that all subsea tunnel concrete used as rock support should be classified as XSA ("Especially aggressive environment") in the same way as for the TF-TSA-PCD sources in Alum Shale. In this respect it is important to note that the complex attack, sometimes being influenced by highly evaporated hypersaline waters, indeed involves TSA and PCD with addition significant impact from magnesium, chloride and acids produced within biofilms.

Finally it should not be forgotten that the rock mass stability conditions represent a very important issue as regards exposure conditions. Inappropriate rock mass classification has up to now led to erroneous design of the rock reinforcement involving sprayed concrete thickness. This practice has caused instabilities and even severe collapse within several modern Norwegian tunnels during recent years. Although chemical degradations are at work and should be monitored for their long term effects, the experience so far is that the collapse situations were not due to low material qualities.

Mitigation and remediation for new constrictions, maintenance and repair

The question is mainly relevant for the attacks from Oslo Alum Shale and saline ground waters. Although the use of high quality concrete with SRPC and SF has combated the severe effects of TSA the process is still slowly working. Studies in the UK have revealed that certain slag cements are even more successful than silica fume [16, 31] and should perhaps also be tried out in Norway. It should still be recalled that revision of a well proven regime sometimes might involve difficulties also to the disfavour of the concrete durability.

The attack in subsea tunnels was in most respects more serious than the present cases of Alum Shale attack. Since steel fibres represent an important reactant in the acid production within the biofilms in an otherwise corrosive subsea environment, it would seem logical to dispense from the use of steel fibres within the mostly leaky subsea tunnels. At least this represents a realistic remediation since there are now several other alternative fibres available on the market. As a matter of fact the Norwegian Public Roads Administration has already specified polymer fibres of non-corrosive material for highly corrosive environments such as in the subsea part of subsea tunnels (cf. Kompen [32]). It is also possible to introduce somewhat thicker sprayed concrete layers than usually specified, because this would slow down water penetration and at the same time serve as a sacrificial layer. A better control and low w/c –ratios might of course also improve the durability.

As regards maintenance work it seems important to remove biofilms systematically where possible. This is not always the case since the sprayed concrete lining sometimes is not accessible through ordinary maintenance procedures.

Repair should when required always involve a thorough characterisation with location of important occurrences of biofilms and identification of degraded sprayed concrete. This should take advantage of geological tunnel maps and rock mass rating charts prepared already during construction. The occurrence and distribution of surface gypsum deposits should be identified and completely removed along with deteriorated concrete, otherwise dissolution of this sulfate will soon take place and lead to sulfate attack on new concrete and also lead to spalling along the old outer surface. Finally the new spray should preferably be made with an inert fibre.

Optimal timing of repair? A general socio-economic approach
It is expected that the most severe deteriorations observed within Norwegian tunnels will lead to a problematic situation earlier than the designed life time of fifty years. An evaluation of the residual life time requires pertinent site specific documentation which may only be obtained through a systematic maintenance scheme, including information on rock mass conditions (Q-value, block movements etc), initial spray thickness, hydraulic gradient and ground water chemistry. Presently no clear cut criteria exist as to where, when and how such a scheme should be applied but it would seem logical to set up a monitoring programme in some tunnels in order to establish deterioration rates. Once having established the rate of deterioration it should be possible to make a socio-economically feasible decision on when to undertake reparation. Indeed the optimal timing of repair is also a site specific problem which depends on the local traffic conditions and a safety analysis. If for example the residual life time of a given sprayed concrete can be estimated to be 20 ± 5 year it would seem most feasible to undertake an operation after less than 15 years both due to public safety as well as for accessibility. Traffic prognoses usually indicate a steadily increasing trend. The consequences of a late repair after about 25 years would certainly involve greater risks as regards traffic safety and transportation costs.

CONCLUSIONS
The present study involved a multidisciplinary investigation of sprayed concrete durability exposed to variably aggressive ground waters. Modern steel fibre reinforced concrete used for rock support in Norwegian tunnels showed chemical deterioration phenomena related to water leakages. Ground waters enriched in sulfate and bicarbonate had caused Thaumasite Sulfate Attack (TSA), detrimental internal carbonation and local acid attack. Concretes subjected to ion poor ground waters were usually sound, although sometimes affected by detrimental internal carbonation or Ca-leaching. Alkali silica reaction was unimportant.

A novel deterioration process was discovered in subsea tunnels within sprayed concrete covered by layered Mn-Fe biofilms. Bio-chemical reactions within the biofilms had caused acidification of the saline waters. Acid resistance of sprayed concrete decreased with time due to simultaneous progressive development of internal carbonation, Ca-leaching, TSA, chloride and magnesium attack. This process was very aggressive and had sometimes caused deep or complete disintegrations of the sprayed concrete after < 5 years.

The most severe attacks involved loss of bearing capacity due to cement paste degradation, steel fibre corrosion involving thinning and strength loss of the remaining sound sprayed concrete. These deteriorations were not only depending on the exposure classes but also on the effect of ambient hydraulic gradients. Depassivation of steel fibres was due to chlorides, acids, carbonation and bacterial action. The life time of significantly influenced sprayed concretes is regarded as less than the design life of 50 years. Yet where rock mass rating had been applied the concrete linings were much more durable. An assessment of residual life time is in each case critically dependent on rock mass conditions, spray thickness, hydraulic gradient and ground water chemistry.

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REFERENCES
1. Franzén T, Garshol, K.T. and Tomisawa, N. (2001): Sprayed concrete for final linings. ITA/AITES Accredited Material: ITA Working Group Report. Tunnelling and Underground Space Technology, 16, 295-309.

2. Barton N., Lien R. and Lunde J. (1974): Engineering classification of rock masses for the design of tunnel support. Rock Mechanics, 6, 189-236.

3. Norwegian Concrete Association (2003): Sprayed Concrete for rock reinforcement. NB Publication No. 7, 78 pp. (in Norwegian).

4. Norwegian Standard NS-EN 206-1, 2003, Concrete Part 1: Specification, performance, production and conformity.

5. Davik K.I. (1997): Proper use of sprayed concrete in tunnels. Parts A, B, C, D, E and Final report, Norwegian Public Roads Administration (in Norwegian).

6. Davik K.I. (1998): Proper use of sprayed concrete in tunnels. Nordic Road and Transport Research 1998-1, 16-17.

7. Hagelia P., Sibbick R.G., Crammond N.J. Grønhaug A. and Larsen C.K. (2001): Thaumasite and subsequent secondary calcite deposition in sprayed concretes in contact with sulfate bearing Alum Shale, Oslo, Norway. 8th Euroseminar on Microscopy Applied to Building Materials, Athens, Greece, 131-138.

8. Romer M. (2003): Detachment of shotcrete linings due to long term interaction with ground water. International Seminar June 2003: The Thaumasite Form of Sulfate Attack, University of Sheffield. 6 pp.

9. Hagelia P., Sibbick R.G., Crammond N.J. and Larsen C.K. (2003): Thaumasite and secondary calcite in some Norwegian concretes. Cement and Concrete Composites, 25, 1131-1140.

10. Norwegian Public Roads Administration (internal documents).

11. Hagelia P. and Sibbick R.G. (2007): Thaumasite sulfate attack, popcorn calcite deposition and acid attack in concrete stored at the "Blindtarmen" test site Oslo, from 1952 to 1982. 11th Euroseminar on Microscopy Applied to Building Materials, Porto, Portugal. 20 pp.

12. Bastiansen R., Moum J. and Rosenqvist I. Th. (1957): Contribution to high light certain construction problems associated with Alum Shale in Oslo. Norwegian Geotechnical Institute, Publication No 22, 69 pp (in Norwegian with English summary).

13. Fiskaa O., Hansen H. and Moum J. (1971): Concrete in Alum Shale. Norwegian Geotechnical Institute, Publication No 86, 32 pp (in Norwegian with English summary).

14. Hagelia P. and Grønhaug A. (2000): Thaumasite – infection causing concrete deterioration. Våre Veger, 9, 54-55 (in Norwegian).

15. DETR (1999): The thaumasite form of sulfate attack: Risks, diagnosis, remedial work and guidance on new construction. Report from the Expert Group, Department of Environment, Transports and Regions, UK, 180 pp.

16. Crammond N. (2003): The thaumasite form of sulfate attack in the UK. Cement and Concrete Composites, 25, 809-818.

17. Hagelia P. (2008): Sources of aqueous sulfate and bicarbonate in Norwegian Alum Shale with implications for concrete durability and geotechnical properties. Submitted to Chemical Geology.

18. Hagelia, P. (2007): Sprayed concrete deterioration influenced by saline ground water and Mn-Fe biomineralisation in subsea tunnels. In: Jamtveit. B. (ed.): Mechanical effects on reactive systems. The 20th Kongsberg Seminar, Norway (Extended abstract/invited talk).

19. Hansen B.O. (1996): Durability considerations related to sprayed concrete in subsea tunnels. Sprayed Concrete in Subsea Tunnels, NPRA Unpublished report October 1996 (in Norwegian).

20. Novak P., Mala R. and Joska L. (2001): Influence of pre-rusting on steel corrosion in concrete. Cement and Concrete Research, 31, 589-593.

21. Dickson W.H., Caccavo F., Olesen B. and Lewandowski Z. (1997): Ennoblement of stainless steel by manganese-depositing bacterium Leptothrix discophora. Applied and Environmental Microbiology, 63-7, 2502-2506.

22. Wigum B.J. (1998): Evaluation of the potential for alkali aggregate reactions in sprayed concrete based on literature studies and international experience. P-533 Durable Concrete Structures. Internal report 2009 Norwegian Road Research Laboratory, 47 pp (in Norwegian).

23. Norwegian Concrete Association (2004): Durable concrete containing alkali reactive aggregates. NB Publication No. 21, 22 pp with appendices (in Norwegian).

24. Harðarson B.A., Wigum B.J., Guðmundsson G., Loftsson M. and Sveinbjørnsson S. (2004): Condition survey of sprayed concrete. Hönnun report. 102 pp (in Icelandic).

25. Bøyeie A.E. (1994): Classification of the rock mass in the RENNFAST tunnels using the Q-method, The RMR-method and the RSR-method. Internal report 1708 Norwegian Road Research Laboratory, 66 pp with appendices (in Norwegian).

26. Hval O. (2000): Comparison of the rock mass rating systems RMR, Q and RMi – experience from practical application in Tåsentunnelen and Svartdaltunnelen. Cand. Scient Thesis, University og Oslo. 230 pp (in Norwegian).

27. Røhrsveen N.G. and Lygre J.K. (1996): Proper use of sprayed concrete in tunnels. Thesis, Norwegian Technical University, Trondheim (in Norwegian).

28. Hagelia P. (1992): Semi-quantitative estimation of water shielding requirements for subsea road tunnels using geological and hydrological data. Internal report 1569, Norwegian Road Research Laboratory, 35 pp.

29. Hagelia P. (1994a): Semi quantitative estimation of water shielding requirements and optimisation of rock cover for subsea road tunnels. In: M.E. Abdel-Salam (ed.), Tunnelling and Ground Conditions, Balkema 485-492.

30. Hagelia P. (1994b): Detection of leakage sensitive joint systems using resistivity measurements in connection with subsea tunnels. In: J. Krokeborg (ed.), Strait Crossings, Balkema, 371-378.

31. Building Research Establishment (2003): BRE Special Digest 1 Concrete in aggressive ground. Parts 1-4. London CRC.

32. Kompen R. (2008): Specifications for sprayed concrete, EN 14487 for sprayed concrete generally, Norwegian Concrete Association Publication No. 7 for rock support and NPRA Specifications for Road Tunnels. In: K. Berg, C. Hauck, R. Kompen (eds.), 5th International Symposium on Sprayed Concrete – Modern Use of Wet Mix Sprayed Concrete for Underground Support, Lillehammer, Norway 21 24 April 2008, 256 -261.

13. DEPOSIT OF INDUSTRIAL WASTE IN ROCK CAVERNS

Tom Myran

ABSTRACT
The use of rock caverns or decommissioned mines as deposits for industrial waste may have practical advantage and is sometimes the only option.

The rock mass in the Nordic countries is by geological standards old and consists to some degree of minerals and rock types that are favourable for storage in view of stability, stress distribution, cracking and hydrogeology. The necessary shielding effect or geological barrier situation is often available; thus the spread of substances that are dangerous to both health and the environment will not take place. During recent 10 -15 years, a number of underground projects have been implemented covering a diversity of products like radioactive and/or toxic waste and industrial waste in general. The operation of such facilities is similar to other underground structures from a technical point of view whereas control and security requirements are different. Regular maintenance is, however completely different, in fact nonexistent in the ordinary meaning. Caverns or sections of caverns will be sealed off and, in-accessible for later maintenance.

This chapter will describe and comment on a number of examples of the selection and use of operational underground storerooms that have been established in Norway in recent years.

INTRODUCTION
In today's modern society there is an increasing need to establish storerooms and waste disposal sites in order to dispose of the increasing amounts of waste (industrial waste, toxic waste, radioactive waste etc.). In this context, a conflict of interests may occur, especially in urban areas. To find acceptable surface areas for the disposal of difficult waste is sometimes impossible. Non-radioactive waste is often disposed of using installations above the ground.

During the 1990s, one began to plan the use of underground storage for radioactive waste. Rock caverns have advantages: availability of space, the geological shielding, the less complicated access control, acceptable investment costs and more.

The depositing of industrial, toxic or radioactive waste underground has for many years been a much debated subject. Norwegians will easily remember the proposals to deposit industrial waste in the closed sulphide mine Killingdal in the county borough of Holtålen (middle part of the country), or to use the closed sulphide mine Tverrfjellet (Folldal Verk AS) in Hjerkinn. Millions of Norwegian kroner were used on design and the initial construction work at Hjerkinn, until Government decided to stop the project.Government also stopped the Killingdal mines project. Finally a go was given to Himdalen in the county borough of Aurskog Høland south-east of Oslo. The Himdalen project is implemented as a combined waste disposal site and storeroom for low and medium radioactive waste with four purpose constructed rock caverns.

STORAGE IN CONNECTION WITH CLOSED OR OPERATIONAL MINES
In the introduction, the suggestions to use the two closed mines Killingdal and Tverrfjellet for storage purposes were commented on. These two examples will be further mentioned later on in this article.

When the sulphide mine (lead-zinc) Mofjellet in Mo i Rana was closed, a waste disposal site for the deposit of industrial waste was established. The mine was closed down in 1987 and the project was initiated in 1993 in connection with the removal of polluted land from the site of the closed coke plant nearby. The pollution consisted of heavy metals and other substances that are hazardous to both health and environment. The substances were moulded and stabilized by mixing cement and plastic substances into a relatively dry concrete. About 60 000 tons of contaminated mass from the coke plant was permanently deposited of in old mining chambers. A total of 1,5 million m3 of ore was produced in the mining period and up to 1 mill. m3 is still available for depositing waste. Today the same kind of mass is received as earlier. This is treated and stabilized into a finished product before it is deposited. The concession limit for storage is 70 000 tons a year.

In 1989, just beside the Mofjellet mines, a storeroom was established in a blasted hall 40 m inside the mountain. Here the National Library is in the process of digitally storing all kinds of historical media productions (music, films and texts). As of today, more than 40 kilometres of shelves containing recording tapes, films, books and newspapers. This work will continue for the up to 25 years, until they have completed the digitalization of all of their historical archives. This digitalization program will cost about 1 billion Norwegian kroner. Nothing short of 1000 years is the time perspective for the digital storage in the National Library's mountain hall in Mo i Rana.

This year (2008) the so-called Global Seed Vault in connection with the mining company Store Norske Spitsbergen Kulkompani AS in coalmine no.3 in Longyearbyen had it's grand opening and attracted a lot of international media. The Global Seed Vault is in many ways a "central bank" for all of the world's seeds. Here one can safely receive and store 4,5 million seeds from all around the world in three blasted mountain halls that are 120 m inside the mountain. The Global Seed Vault should be safe from any climate changes and a subsequent raise in sea levels. The permafrost is a safeguard against power failures. The first beginnings of what was to become the Global Seed Vault were established back in 1984.

The copper-zinc mine Tverrfjellet which is situated 1100 m above the sea on the Dovre mountain plateau was closed down in 1993. The Ministry of the Environment was at the time on the lookout for a provisional storeroom to deposit industrial waste in. One of the alternatives was Tverrfjellet which is near the railroad route between Trondheim and Oslo, and had a lot of the necessary infrastructure both above and below the ground in place. For example a transport system, ventilation, pump system and surveillance system for pollution (smoke and gas). The technical (stability) and mechanical (tension) mountain rock conditions with regards to the ore deposit and mountainside, in addition to the groundwater conditions, were all considered good. There was a suitable arrangement for the transport of the waste by train directly into the mine, then further transport down a vertical shaft and transport spiral to the storage facilities at a depth of 600 m. Two vertical mountain halls with a total volume of 12 000 m3 were made for this purpose. The halls are beneath the groundwater level and this will lead to a positive water pressure gradient in relation to the storage halls. A total investment of around 10 million kroner was used in the preparation of these storerooms.

The plans for a waste disposal site were strongly criticized by environmentalists. One of the arguments was that it was unacceptable to have a storeroom for toxic waste that was localized and had a transport system that was so closely connected to Dovrefjell National Park. In addition, the acid environment in the mine connected to the mineral composition was also mentioned as one of the main disadvantages. Based on critical comments from environmentalists, the Ministry of the Environment decided to postpone the plans. This lead to the dismantlement and disassembly of the installation and in total it cost of 25 million kroner. In hindsight, one could now say that establishing a special storeroom in the Tverrfjellet mine with the given conditions, was a good suggestion that would have worked very well within reasonable limits.

In connection with the rock company Fana Stein og Gjenvinning AS in Stendafjellet just outside of Bergen, a storeroom for industrial waste was established. The company originally started as a mass withdrawal and a stamp mill above the surface, but in 2001 they went underground with the stamp mill production in stopes (halls) planned to become 140-250 m long, 50 m high and up to 25 m wide. Today only hall 1 is completed to deposit lightly polluted mass and industrial waste, with a minimum content of organic material. Altogether 8 storage halls are planned. Gradually, as the halls are constructed the depositing begins. Simultaneous underground rock production combined with waste storage, will have several advantages. As the cost of establishing the halls will be covered by the rock production, the net investments for the waste disposal will be moderate. All in all it is about establishing leachate accumulation and a surveillance system connected to this. Limits have been set regarding the content of heavy metals and other types of pollution in the waste. The total storage capacity is over 3,5 million tons. With a concession of 150 000 tons per year the installation will have an operation span of over 20 years.

STORING IN MOUNTAIN HALLS THAT ARE BLASTED FOR THIS PURPOSE.

Instead of using old mines or rock caverns, depositing waste can also be carried out in rock caverns that are excavated, dimensioned and adapted for this purpose.

In the mid 1980s, a large-scale deposition of toxic waste began in rock caverns for Norzink AS in Odda (now Boliden Odda). The background for this was that industrial waste from zinc production had previously been pumped out into the Sør Fjord, one of the side fjords of the Hardanger Fjord. This led large amounts of silt containing heavy metals (jarosite) into the sea. This practice was terminated. The caverns have a cross section of 375 m2 and a volume, depending on the length, varies from 70 000 m3 to 140 000 m3.

Since 1986, the pollution of the fjord has been dramatically reduced and the quality of the water has been declared restored.

The smelting plant Falconbridge in Kristiansand has also established a disposal site/storeroom in rock caverns for the industrial waste scoria from the melting plant. Until 1982, this waste was mixed with seawater and deposited at the bottom of the sea via a pipeline. Then the Ministry of the Environment put a stop to this practice and the company developed a waste disposal site on land. 10 years later the company wanted to further expand this land deposit, but this was not accepted amongst other things because of worries and complaints from neighbours and the surrounding area. The mountain halls were put into operation in 1993 and at that time consisted of two halls measuring 11 000 m3 and 34 000 m3 for the reception of a scoria rich in both lead and iron. The number of halls has been further expanded.

UNDERGROUND STORAGE OF RADIOACTIVE MATERIAL

Waste disposal site for low and medium levels of radioactive waste

In 1992 a consequential investigation was carried out concerning the establishment of a waste disposal site for low and medium levels of radioactive waste in Norway. Three localization alternatives were discussed.

Killingdal mine (closed down) in the county borough of Holtålen, in Sør-Trøndelag. 950 m under the surface. Dependant on a lift. New mountain halls needed to be blasted because the current mining chambers were unsuitable.

- Kukollen in the county borough of Sørum, in Romerike/Akerhus. The establishment of a mountain hall. A mountain cover of about 50 m. Entry via a tunnel that you can drive through of about 150 – 190 m.
- Himdalen in the county borough of Aurskog-Hølan, in Romerike/Akerhus. Establishment in the mountain. Mountain cover and entry is the same as for Kukollen.
- One of the main requirements for the disposal site is that the waste (the waste barrels) must be protected from water penetration and decomposition. In principle this requires a dry mountain chamber and consequently a safe drainage system.

The fundamental principle for the deposition of radioactive waste is that any leak into the biosphere is delayed until activities or radiation doses are at an acceptable level.

Based on the geological and hydro-geological premises, Killingdal was considered completely unsuitable and no longer of any interest as an alternative for the waste disposal site. This was especially related to the mine's extremely corrosive environment (acid sulphide minerals), that measures against leaking surface water and groundwater would be difficult to maintain over a long period of time. In addition, the distance, transport, climate, cultural monuments and outdoor sports activities all worked against Killingdal.

Few things differentiated the other two alternatives from each other. The group in charge recommended that the waste disposal site should be situated in Himdalen. They did not recommend that the closed down Killingdal mine should be selected as a waste disposal site.

Himdalen was put into operation in 1999 and is a mountain installation with four halls for waste and a 150 m entrance tunnel. In each hall two concrete sarcophagus have been built that each consist of floors and walls. The plan is for the installation to be in operation until the year 2030. Then the halls will be refilled in such a way that the drainage system will still be able to function for a long time to come. The overall requirement is that the waste barrels must be protected from water penetration and decomposition. There is a planned institutional control period of 300-500 years, including surveillance, measurements and limitations of the use of the area surrounding the disposal site. Highly active waste, used core fuel, strong sources of radiation, radium needles and scale from the production of oil (generated after 1.1.1996) will not be placed in Himdalen. Neither will waste from abroad (Radiation protection Info. 1-08).

PERMANENT DISPOSAL SITE FOR RADIOACTIVE WASTE FROM PETROLEUM OPERATIONS

In March 2008 the Norwegian Radiation Protection Authority (NRPA) gave their approval for a permanent underground rock store for radioactive waste (TENORM = Tecnologically Enriched Natural Occurring Radioactive Materials) from the petroleum activities on the Norwegian continental shelf. The entire disposal site will be placed underground and will consist of a "tunnel that will treat the waste and an entrance tunnel that will lead to two disposal tunnels (Radiation protection Info 1-2008). The facility is the first of its kind in the country, has a capacity of 6000 tons and is situated by Stangeneset industrial area in Gulen in Sogn og Fjordane.

So far 400 tons were temporarily stored in 8 NRPA approved installations, all placed on the western coast of the country. Due to increased decommissioning of offshore installations it is assumed that a quantity above 3000 tons must be stored during the next 30 years

Internationally one can find many installations of this kind. Both Sweden and Finland deposit low and medium active nuclear waste in excavated rock caverns in similar rock types.

Reports from several analyses and project studies have been concluded on the possibility of storing nuclear waste and other kinds of hazardous waste in underground rock caverns. Examples are the closed Stripa mine and the Äspö rock installation in Sweden. Reports have been prepared concerning highly active waste storage. The reports cover different types of rocks and geological environments. Most reports concern crystalline rock types, but reports on storage in volcanic rocks and salt formations are available.

GENERAL COMMENTS TO THE SITE SELECTION FOR AN UNDERGROUND STORAGE FACILITY

In principle there is not much difference between the planning of a storage/disposal site for toxic waste from a more conventional storage facility. The conditions relating to the place, the orientation, the design and dimensioning are important in order to achieve an optimal solution. If a closed mine is chosen the basic lay-out, the same applies to conditions like stability, geology and hydrogeology. Important aspects will be: the division of the rock types and their characteristics like, cracks, fissures, weak zones, the rock stress, geochemistry etc.

Certain geochemical conditions that should be mentioned are: some dissolved minerals, i.e. calcite ($CaCO3$) can in acid water form karstic minerals, whilst others can be oxidized and form aggressive / corrosive environments (i.e. pyrrhotite ($Fe1-xS$) in oxidized environments can form sulphuric acid). Other rock types and minerals may have favourable effects. One example is zeolite minerals that are known to have a favourable radion-absorbing effect in connection with the storage of nuclear waste.

Amongst other hydro-geological conditions, permeability is an important factor for the unintended transport of dangerous substances from the storage, mainly via groundwater. Frequent observations are a downwards decrease of the permeability and a relation between the strength of solid rock, crack/rift character and permeability. Stiff crystalline rock types (i.e. granite and granite gneiss) often have relatively few, but open cracks and therefore a high degree of permeability. Weaker rock types (i.e. phyllite and mica schist) are usually more closely cracked, but the cracks communicate to a lesser degree. Permeability is therefore lower.

In old mines, blasting work in connection with modification work may cause changes in the rock's mechanical, chemical and hydraulic characteristics, such as the formation of crack, increased permeability etc. Cautious work is hence adviceable.

The safety concerns related to the handling of dangerous materials is closely connected to the characteristics, the amount and the accessibility. This also applies to the final storage of radioactive material. By storing it in rock deep down, the aim is to take advantage of the rock's shielding effect against the spread of materials that are dangerous to health and environment, the so-called "geological barrier". Hazardous waste in less than ideal geological conditions will mean that in addition to the geological barrier, one will also need a carefully planned system of artificial barriers like concrete walls, membranes or metal containers. An example of the multiple barrier principle is shown in fig.1.

SELECTION OF THE FINAL DISPOSAL SITE FOR NUCLEAR WASTE.

The principle guiding the selection of the final disposal site for nuclear waste is that it should be isolated in a safe place during the time the waste has a higher degree of radio-toxicality than can be found in nature. Applied nuclear fuel contains large amounts of radioactive substances. Most of these are active during some hundred years only whereas uranium and its bi-products still remain active for say 1000 years, and a few long-lived substances such as plutonium has an extremely long half-life. After well over 100 000 years the fuel's radioactivity has decreased to a level that can be compared to the level of uranium ore. Radioactive waste is grouped into three main categories: highly, medium and low active waste. Norway has no nuclear power and the amount of highly active material is very small. The problems connected to the storage of radioactive material are therefore connected to low and medium active waste.

FUTURE STORAGE POSSIBILITIES IN CLOSED/OPERATIONAL MINES IN NORWAY

After 400 years of industrial mining, there is a number of closed down mines. Consequently caverns are abundantly available with large volumes for storing of different kinds of waste and polluted mass. During the recent 10 years systematic investigations have been carried out in order to assess the storing options.

Examples:
North Cape Mineral: Mines Stjernøy, Bryggja, and industrial minerals
Norcem Brevik, Kjørholt
Røros copper works.
Nordal Olivin
Labrador in Larvik
Several closed down minor mines with limited volume can be found.

Boomer E-series and Tunnel Manager MWD

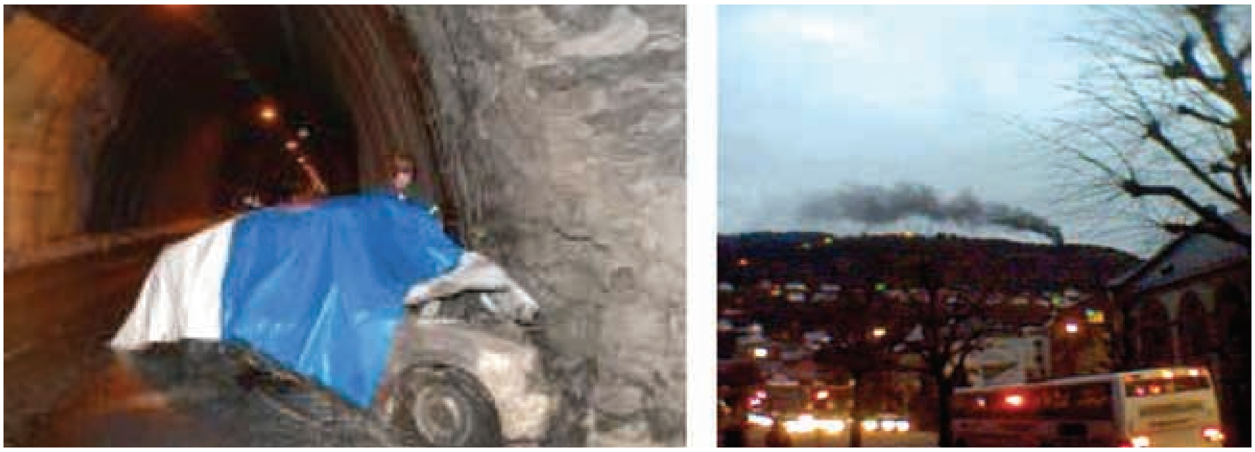
Tunnel Manager MWD (Measure While Drilling) is an instrumentation and software for recording and interpretation of drilling data and enhanced presentation of geo-mechanical variation of rock ahead of the tunnel face.

One of the most difficult, yet extremely important steps in drifting and tunnelling is to predict the geological and geo-mechanical variations ahead of the tunnel face, particularly in stretches where rock formations are expected to vary considerably. An advance awareness of geo-mechanical properties ahead of the face can save large amount of valuable time and money and improve safety, by allowing to take appropriate measures before reaching the difficult and dangerous formations.

The Tunnel Manager option with the MWD module is designed to be used on modern Atlas Copco drifting and tunneling Boomer rigs with Rig Control System (RCS) and equipped with the optional function Advanced Boom Control (ABC), Regular or Total.

14. FIRE IN THE FLØYFJELL TUNNEL

Gunnar Gjæringen



Left: The wrecked car. The driver was killed. No passengers in the car. Right: The fire could be observed from far away.

INTRODUCTION

This paper concerns a car accident in the downtown Fløyfjell tunnel in Bergen city on the west coast of Norway that happened 10. November 2005. The driver lost control, hit the tunnel wall, causing a fire with fatal consequence. The data provided are based on the records of the local Traffic Control Centre (VTS), the Bergen Fire Brigade and the Police precinct with additional information from the responsible section of the Roads Authority.

To overcome water, frost and ice problems, most road tunnels in the country are protected by capped insulation. During a period of several years the installed frost insulation material frequently used to be polyester foam. Convenient, efficient, easy to install, agreeable cost, however, bad from a fire protecting point of view and now banned from use.

THE TUNNEL

The Fløyfjells tunnel has 2 tubes with each two lanes, the tunnel lengths are 3195 and 3825 meters respectively. The AADT is approximately 17.000.

The tunnel is equipped with remote controlled signals outside the portals, there are emergency telephones and fire extinguishers for every 350 meters, longitudinal ventilation and 500 meter high exhaust shafts placed approximately 500 meters inside the portals. There are fireproof door-closers. Water tightening by PE-foam mats: southbound 29.400 m2, northbound 32.500 m2

The tunnel sprinkler system is divided into 11 zones. Each nozzle is activated at 59 ° C.

One of the zones is equipped with a water-fogging device whereas the entire system (i.e. all the nozzles of the activated zone) sprays the tunnel with a dense, small-particle fog. The zone is activated also at 59 ° C by the heat-detecting cable.

The sprinkler and water fogging systems are “dry systems”. That means the pipes in the tunnel vaults are empty until the water is turned on when activated by the detection cable.

OBSERVATIONS

- Below points worked according to the plans:
- Warning signals from the open-door sensor in the emergency cabinets.
- Warning signals from the sensor detecting a removed fire extinguisher.
- Warning signals from the off-hook sensor on the emergency telephone.
- Warning signal from the sprinkler system activation.
- The sprinkler system
- Alarm call from the VTS to the rescue departments (Police, Fire and Ambulance)
- Activation of closing procedures.
- Ventilation
- Activation of fireproof door-closers in emergency passages.
- All emergency installation worked as they should.
- Communication between the rescue teams and personnel from Statens Vegvesen.
- Commuters and other present civilians helped in any way they could, and acted with exemplariness.

BELOW POINTS DID NOT WORK ACCORDING TO THE PLANS

- The fireproof doors in the emergency passages were difficult to open.
- There were too few fire extinguishers (after the upgrade to be completed by spring 2004 there will be two extinguishers for every 60 meters).
- Journalists created dangerous situations by their badly parked cars, and by their general behaviour around the scene of the accident.
- Heavy traffic created problems for the rescue teams and slowed their progress.
- The parallel (northbound) passage was not utilized for rescue purposes.
- The means of internal alarm notifications within Statens Vegvesen must be further discussed.
- Break-in messages to the commuters on radio frequencies (not yet ready)

The complete costs relating to destroyed material and clearance work in the tunnel (not covering the work of the rescue departments) has been estimated to NOK 200.000,- (approx. USD 30.000,-).

Safety improvements:

Emergency break-in message to commuters via the radio frequencies on the national and local radio channels
Emergency telephones in the tunnel
Longitudinal mobile telephone aerial in the tunnel vault
Communication trunk to the rescue departments
Red stop signals for closing the tunnel.
Gates for closing the tunnel.
10 emergency passages to the opposite tunnel.
2 larger emergency passages for evacuation of vehicles to the opposite tunnel.
Signs identifying emergency exits.
Fire extinguishers
Fire protection of PE-foam. New sprinkler system. A water-fogging system is installed in one zone for testing.
Upgraded higher capacity ventilation system. Longitudinal ventilation with shafts in each end.
Water supply at each emergency passage.
The tunnel is connected to the VTS.
Emergency control cabinet near the tunnel mouth.
Emergency plan with a risk analysis and an action plan for the Fire brigade.

Fire protection of the Fløyfjells tunnel is part of the upgrading programme imposed by the Fire Brigade on the Roads Authority for all the tunnels in the Bergen area. The upgrading programme aims at a standard as required today. [Interested readers may download the actual regulations from handbook o21 for road tunnels (English version] on www.tunnel.no]. The upgrading of the Fløyfjells tunnel has taken place.

The predefined action plan for the fire brigade in the event a new emergency situation is for resources from Sandviken fire precinct to head to the north end going south, while firemen from the main station head for the southern portals.

THE ACCIDENT

The car that caused the incident was an old Opel Ascona (aka Vauxhall) travelling south-bound hitting the left wall, bounced back to the right wall before again hitting the left wall with a powerful impact. The accident happened about 1000 metres from the portal, fairly close to an emergency opening designed for emergency car passage.
There were no other cars near the accident car when it hit the walls. Due to injuries and car damages the unlucky driver was unable to leave the wreck.

The car caught fire, other motorists soon to arrive, tried in vain to extinguish the fire using available handheld equipment. The fire was beyond control when the firemen arrived.

The fire had spread to the PE-foam mats on the tunnel wall, some 3-4 square metres had caught fire; the sprinkler system was activated and suppressed the car fire itself as well as the adjacent fire in the PE-foam.

The accident occurred during rush-hours. The southbound tunnel and nearby roads were jammed within minutes.
To underscore the rapid development, some recorded details:

16.21: Alarm on OS 32 indicating that a fire extinguisher had been removed and an indication that a door on an emergency telephone booth had been opened at locations 1103, 1104 and 1113. An indication that the sprinkler system had been activated was also seen. All these alarms went off at the same time.
16.22: The fireman on duty calls and asks that the tunnel is closed as there is a fire in the tunnel close to the exit near the town centre.
16.23: Tunnel closed (blocked for further vehicles)
16.24: The traffic lights downtown area changed to rerouting mode (reflects traffic pattern while tunnel system closed).
16.31: The fans set to manual control, switched to emergency for southbound tunnel as requested by the fire brigade.
16.31: A message was sent on the radio”vita” that the tunnel had been closed in both directions and posted on list B.
16.32: Head of the district road administration notified.
16.48: Emergency stand-by officer notified.
16.42: The chief fireman on duty requested the fans to be switched to emergency level in the northbound tunnel, as there was smoke in the tunnel vault. The fans in the southbound tunnel were turned off.
16.45:: The northbound tunnel, right lane opened – reduced speed. The traffic lights were changed according to the action plan.
16.57:: The smoke cleared from the tunnel. The Police requested the fans be reset to automatic in the southbound tunnel.
17.09:: The left lane of the northbound tunnel reopened. The fans set to automatic. The speed limit 60 km/h.
17.11: Radio: The northbound tunnel opened.
17.15: Road Authority instructs Contractor to undertake necessary work.
18.29:: The fans were set to automatic towards the shafts.
18.59: The tunnel light system reset in the entire southbound tunnel.
19.00: Removal of corpse from the car.
19.34: Traffic back to normal.
19.55: Stand-by crew on duty.
23.45: Estimated reopening of the entire system to 02.00
05.00: The tunnels opened

CLEARANCE WORK

The fire was put out shortly after the fire brigade arrived. The rescue team quickly concluded that the person in the car had not survived; the car was covered with tarpaulins. Representatives from the press took pictures.

The clearance work could start.

- Present in the tunnel was people from the Police, the fire brigade, Statens Vegvesen, a forensic team, a funeral agent and an emergency car rescue company.
- The Police made the necessary investigations on the in order to secure evidence that could point towards a conclusion on the cause of the accident. This work was extensive.
- The fire brigade commenced with the process of removing the victim from the car. The car was stretched and parts of it were cut away. The casualty was transported to forensics institute.
- The wreck was removed from the scene.
- The road surface was hosed and cleaned.
- Mesta, as the contractor for tunnel maintenance, performed the remaining clearance work, dismounting and preparation of the sprinkler system, replacement of damaged air-hose, refitting of the electrical equipment and refitting of the control system and cables.
- The tunnel was closed for 12.5 hours from 16.20 to 05.00.

Damages and repairs

- One emergency cabinet with a fire extinguisher and an emergency telephone and a distribution box for 4 other emergency cabinets were destroyed as a result of the impact.
- As a cause of the fire, 2-3 m2 of the watertight sealing material – PE – was damaged.
- The air hose for the sprinkler system was damaged and had to be replaced for 20 meters.
- 10 sprinkler heads were used (melted) and had to be replaced.
- The sprinkler system was dismounted and prepared for reinstallation.
- The tunnel was cleaned.
- Estimated total expenses for repairs was NOK 200.000,-

LESSONS LEARNED?

- A tunnel fire may have disastrous consequences.
- Early arrival of efficient fire fighting resources is crucial. In this context it is a matter of few minutes, say less than 5. On this occasion, it took 6 minutes from alarm until the first team from the fire brigade arrived.
- An immediate message from the scene of a fire incident improves the position of the rescue squads
- Tunnel closing procedures must work, as they did here.
- The use of driveable emergency crosswise passages is important both for rescue and evacuation purposes. On this occasion, all smaller vehicles were guided through these passages and into the opposite tunnel.
- Ventilation must be responsive and efficient, like it was in this situation. It is crucial that the sprinkler system is activated and functional immediately, like it was here. The emergency equipment worked as a first means of support like it should. The efforts of civilian motorists can be vital for the outcome of an accident.
- Proper routines for operation and maintenance are of crucial importance for all the equipment to work at all times. The documentation of routines and schedules is very important.
- Sufficient access for the fire brigade is of significant importance.
- The use of the emergency openings between the tubes is important for the accessibility for the rescue parties.
- If the tunnel had been designed in accordance with requirements today, the rescue teams would probably have reached the scene of the accident at an earlier stage.

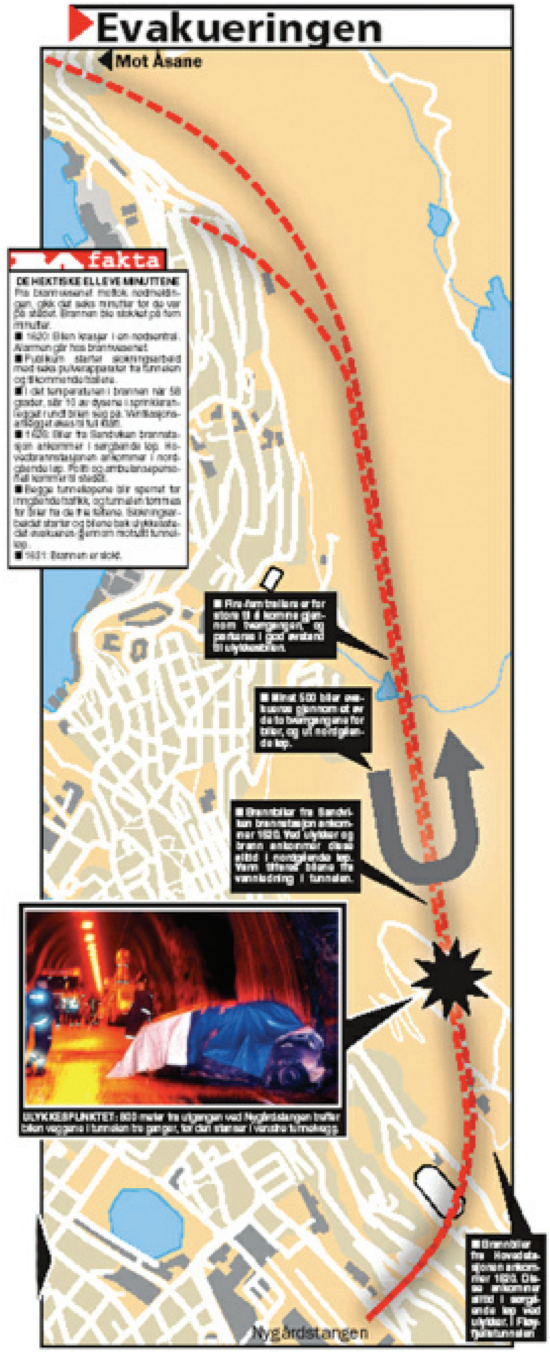


Illustration from the local Newspaper "Bergensavisen"
The incident caught the newspaper headlines for several days.

15. THE INFLUENCE AND EFFECT OF OPERATION AND MAINTENANCE ON THE DIFFERENT PHASES OF A NORWEGIAN ROAD TUNNEL

Gunnar Gjæringen

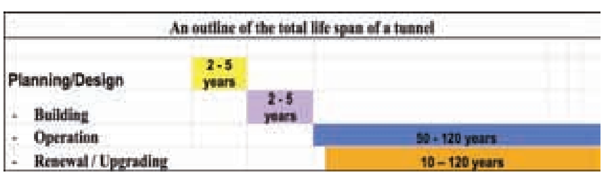
INTRODUCTION

It is important to design and build a tunnel for easy and cheap maintenance. The experience from the operating and maintenance phase of tunnels are to be transferred to the people who are planning new tunnels. In that way they can take this information into account.

An operational and maintenance function must contribute positively in relation to the expenses that have been used. There is only one way the operation and maintenance department can contribute in this context, and that is availability concerning the flow of traffic. An optimal effort is therefore required in order to accomplish this.

Conditions affecting tunnel maintenance are already determined from the start of the planning process of a tunnel. Already in the early stages of planning, as one starts to describe the design of the tunnel, the conditions that can affect the operation and maintenance has to be known.

The standards and solutions that are chosen, will always influence future operational procedures and maintenance requirements. A tunnel will, in the same way as any other section of a road, go through different stages. Altogether this amounts to the total life span of the tunnel.



The above figure gives a general description of the relationship between the different stages of the life span of a tunnel.. However, there are great differences when it comes to the length of time in which the different parts of a tunnel will last. The actual structure / tunnel construction is expected to last up to 80 – 120 years. This is 20 to 30 times more than the time it takes to plan and build it. Therefore, technical solutions that cause the operation and maintenance to become some more expensive, will over the given time period accumulate into large amounts of money.

Technical equipment has a shorter life span or length of function than the actual tunnel. Surveillance equipment and other forms of electronic equipment will often have an economic life span of approximately 10 years, and for certain components the time is as low as to 5-6 years. When technical solutions are assessed and compared to each other, it is therefore important to consider the costs according to the total life span, (LCC : Life Cycle Cost)

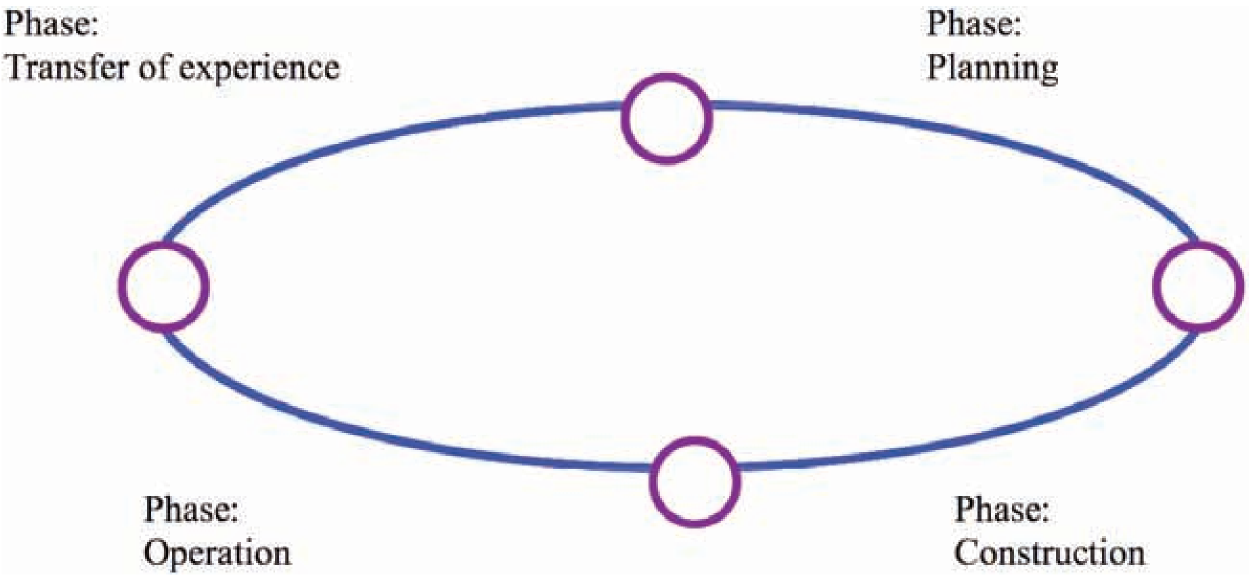
Considerations of *Life Cycle Costs* should be used as a starting point when choosing technical solutions, equipment and installations during both planning and construction, and in connection with renewal.

In some cases, operation and maintenance start before the tunnel is completely finished. This occurs when the period of construction lasts for several years. Installed equipment and components must be maintained as soon as they are assembled, even though they are not in operation.

It is normal, throughout the tunnel's life span to install or change the equipment because of wear, damage or alterations in requirements. This is done in order to prolong the total life span, or increase safety measures. In addition, the overall economy is a crucial element when considering replacing and/or investing in new equipment.

A few years ago it was stated that 80% of the maintenance costs in the field of industrial processes, were determined by people who had no knowledge of, nor were interested in operation and maintenance. There is no corresponding survey for tunnels, but there are a number of similarities between a tunnel containing a lot of equipment and a small processing plant.

It is therefore of great importance that the experiences of those who are responsible for the operation and main-



tenance of the tunnel, are conveyed back to the people that are planning and constructing the tunnel. Only in this way will this experience be directly of use the next time a new tunnel is being built, or a tunnel is being upgraded.
This cycle will also form the basis of a common utilization of all the competence that can be found in the surroundings, and that will benefit the project owner.

PLANNING PHASE:

Administration
Formal clarification for public road constructions in Norway, including road tunnels, is first and foremost regulated by the Planning and Building Act (PBA). The regulations in this act concerning planning and construction procedures are of great importance. Important sections of the formal basis are also directed according to PBA regulations. This particularly applies to:

- regulations relating to environmental impact assessment
- regulations relating to procedure and control in building matters

Other PBA regulations regarding:

- requirements relating to structures and products for structures.
- the approval of enterprises and the right to accept responsibility
- the organisation of the central system of approval concerning enterprises and the right to accept responsibility

In addition to procedures given by the PBA, it might also be necessary for some tunnel installations to clarify the rules in other regulations regarding conditions to certain special regulations.
A particular concern for tunnel installations is considering whether there is a need for clarification according to the Pollution Act. One must also take into consideration the requirements of the Working Environment Act and its regulations.

TECHNICAL ASPECTS

The feasibility of the tunnel project should be considered and a rough cost assessment should be drawn up. It is essential, from an operational and maintenance viewpoint, that LCC-calculations form the basis of choices of solutions and that the maintenance accessibility of the solutions are emphasized. Choices that are made at this stage will directly determine both the conditions for and consequences of future operation and maintenance.

Typical conditions that must be investigated at this stage are coverage of critical sections and the positioning of the tunnel opening. Both of these will be of interest for the conditions of future operation and maintenance. Especially the positioning of the tunnel opening will have a great impact on both the cost of the operation and the consideration of traffic safety.
At this stage, the MOM (Maintenance Operation Management system)-program can be included as an administration system. This is to raise consciousness about and make more apparent the responsibility of ownership for future installations.

Knowledge about operation and maintenance and the choice of maintenance-friendly solutions must be included in the planning phase.

PROJECT PHASE

Administration
Establish a project group where traffic authorities are a natural and responsible part of the group. All of the requirements and specifications that are chosen should be assessed according to the consideration and

availability of operation and maintenance. The chosen solutions should also to a great extent be predictable in a future operational and maintenance phase. The best way to ensure this is to attach greater importance to the life cycle costs of the different tunnel elements.
Clarification from the fire department and the preparation of accident preparedness plans in consultation with rescue departments.

Technical
Requirements regarding competence about operation and maintenance at all levels concerning the preparation of descriptions are to be made.
In this connection, it is especially important that the electro-competence is attended to. This kind of competence presupposes experience with operation and maintenance. Electronics plays a major part in the operation and maintenance of tunnels and involves both highly cost-demanding investments and corresponding operational and maintenance expenses. Knowledge about available maintenance solutions and equipment is therefore extremely important.
Functional requirements to geometric solutions and technical installations are to be made.
It is required that all of the documentation and any procedures and descriptions that might be of importance for future maintenance, should be prepared and submitted in such a way that it can be entered into the department's standard MOM-programme.
Requirement regarding the recognisation of tunnels in the same class are to be made.

The positioning and design of toll plazas must be assessed in view of the Health, Environment and Security (HES) - and flow of traffic considerations. The design must also guarantee available operation and maintenance (sufficient width of the road for the passing of winter maintenance equipment, ploughs, etc. and wide transports).

CONSTRUCTION PHASE

Administrative
The project group should continue its work into the building phase.
This is especially important considering that traffic should be "maintaining" operational- and maintenance considerations all the time, throughout an active building phase. The future owner of the installation should have a high influence in all of the circumstances which concern changes in accepted plans. Substantial changes that are of definite importance for both life span and life span expenses should be discussed according to such considerations and the consequences should be investigated and accepted. It is important that the future owner is attending site meetings and in this way makes the "ownership-responsibility" of the future installation visible.

Technical
Any changes in previously used technical solutions should be made in consultation with the future owner from the viewpoint of operational- and maintenance considerations.
Decisions that are closely connected to the field of electronics should be based on electro-competence and electro-experience from operation and maintenance.
Documentation is needed in connection with the standard MOM-program.

ACCEPTANCE PHASE

Administrative
The main purpose of an acceptance is to make sure that the tunnel is built in accordance with the accepted plans and any approved alterations, and furthermore that the workmanship and equipment are in accordance with these. Any defects should be registered and a deadline for improvement should be set.
Standard procedures for this kind of acceptance should be prepared and participants defined.

Technical
All relevant documentation that concerns the tunnel from the planning phase to the completed building phase should be included in the acceptance. Documentation for technical installations should also be delivered as computer files that are compatible to the standards of the owner. It is also an objective that the documentation of all of the geometrical solutions exist as compatible computer files.

OPERATIONAL- AND MAINTENANCE PHASE

Administrative
The systematic maintenance is organized according to a precise and experience-based correct description of the work routines that should to be carried out with the help of the MOM-programme. Active use of the accumulated experiences to evaluate the routines in order to continuously optimize the maintenance procedures. Organize the use of the MOM-program in such a way so that it achieves an understanding of the why the MOM-program should be used and the value for the owner in making use of a collected transfer of experience.

Technical
Follow-up through a MOM-program and use the experiences to continuously assess choices and solutions. Consider the consequences of life span expenses based on experiences and consequential changes in choices and replacements.

TRANSFERRAL OF EXPERIENCE

Transferral of experience is to make sure that good solutions are made even better, more maintenance-friendly and more cost-effective. A continuous recurrent cycle where operational- and maintenance experiences are supplied to the planners and constructors in a structured manner, is a prerequisite for such a development. Improvements are made through experience.
Experiences also form the foundation for the improvement of manuals and guidelines. Manuals must be continuously updated and not only revised after a number of years. It is also important that the connections between the different manuals are attended to and that any conflicting and/or non-clarifying consequences are solved.

THE MOTIV-PROGRAM

In order to obtain a sound solution to the different phases, and enough funds for operation and maintenance, one is dependent on the fact that the method that governs the allocation of the funds is correct. It is a prerequisite that all the road elements of the tunnel are included in this method, and are correctly weighted according to the actual experience costs. MOTIV is a programme which delivers cost estimates of operation and maintenance to each tunnel. This is done from an evaluation of the complexity and the class of each tunnel.

The MOTIV program must be cost index regulated every 4 years.

The development of a price index must be added with an automatic annual adjustment.
Allocation must be increased, and be 100% of what the program indicates.
New tunnels/changes in road elements must give 100% disbursement during allocation.
New regulations such as the alteration of height and width of large vehicles must be automatically added to the basis of the method.

MANUALS

The owner's manuals should specify the work during the different phases.
In order to secure such specifications and that the technological development is taken care of, it is a prerequisite that the manuals are continuously updated at least every 5 years. Deviation routines should be clarified before the manual is in use.

Updates / changes in the manuals that will have consequences for other manuals, must lead to automatic changes in these manuals. Other decisions or regulations that are of importance to the manuals, must lead to an automatic change of the manuals.

16. EXPERIENCE TRANSFER

Gunnar Gjæringen

INTRODUCTION

This paper is based on findings and recommendations by an internal project group in the Norwegian Roads Authority.

The selection of the best method and the best suitable machinery or equipment with a view to optimal life time costs will become increasingly important. To achieve this, the estimate of operational and maintenance costs must take place as an integrated part of the procurement process. Available theoretical models designed to ease and improve the analysis are helpful for the planning of new tunnels and for the upgrading of existing facilities. Through the systematic use of the model, one can assess and compare technical solutions before decisions are made.

The aims are:
Good quality for the users
Agreeable overall costs
Long life cycle of constructions and equipment
Short down time of tunnels for maintenance work
Good operational accessibility and operational safety
Best safety level

The end result depends in dominating degree on the decisions made during the planning stage. The selected construction methods and the quality standard of the machinery and equipment have a substantial influence on the costs during the operation and maintenance phase. As always, competence, experience and teamwork are good tools

The benefit when using models as decision-making tools depends on good quality and consistent input. In lack in exact information, one is left with estimates based on history, experience and professional judgment.

To achieve an optimization of the operation and maintenance in a tunnel some preconditions should be underlined: easy access to installed equipment, maintenance-friendly solutions and standard exchangeable components.

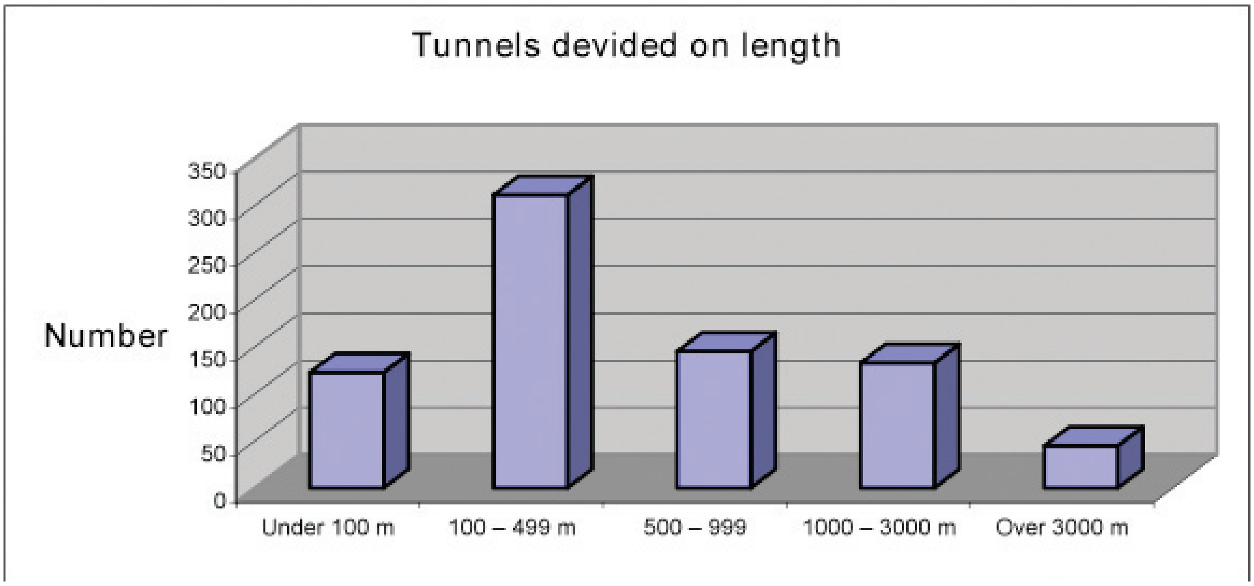
OPERATION AND MAINTENANCE

General information

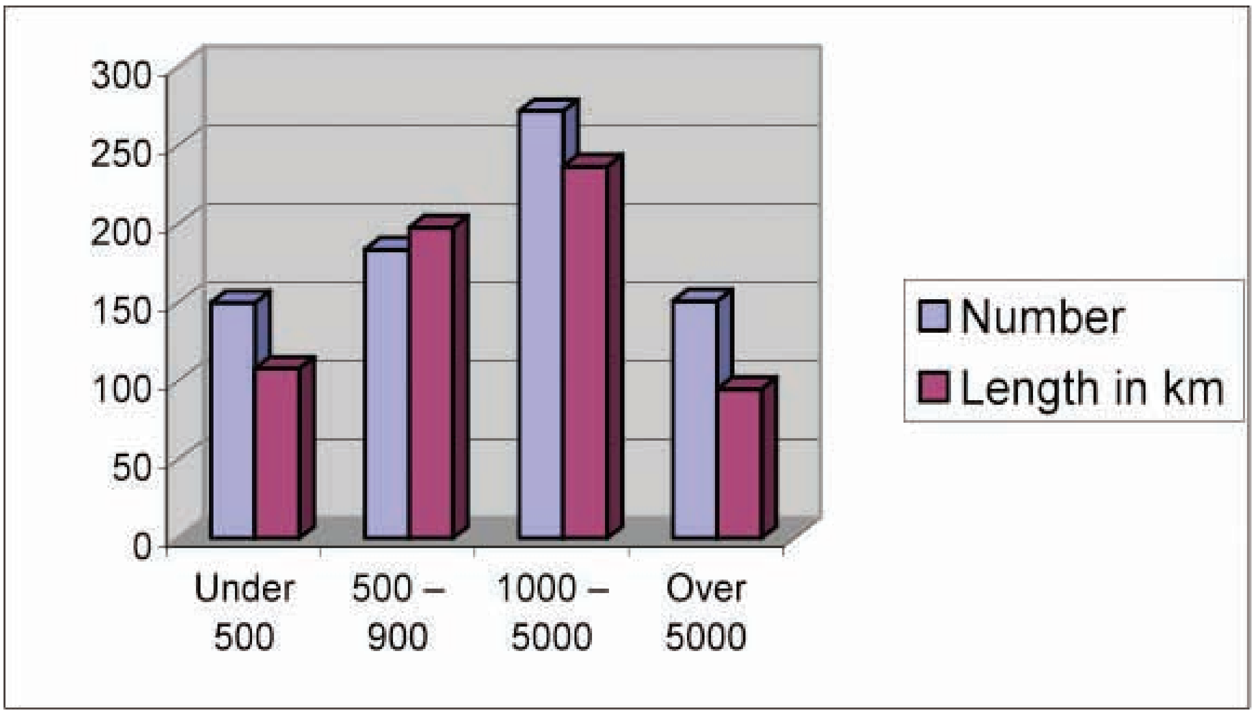
On the national road network in Norway there are close to 1000 tunnels. The majority has a length of less than 500 metres, some 350 are longer and again 50 of these more than 3.000 metres and 3 more than 10.000 metres. The longest road tunnel in the country today is the 24.500 metres Lærdal tunnel in Sogn og Fjordane.

There are 22 underwater road tunnels in operation. The Bømlafjord tunnel, maybe the world's longest, at 7.888 metres. The runner up Eiksund of 7.765 is also the deepest, down to 287 metres b.s.l. Additionally tunnels will be found on the county road network. Few of these are longer than 3.000 m.

The total "value" in terms of re-acquisition costs of the road tunnels in the country is estimated to be around 35 billion Norwegian kroner. The Public Roads Administration, responsible for maintenance, receives a budget allocation from Government (taxpayer's money) for tunnel maintenance that is determined through a calculation program called "Motiv" . The allocation of about 210 million kroner a year is based on unit prices, maintenance items and the frequency of necessary actions. Today's politics is to reduce allocations connected to road traffic, thus smaller amounts are granted than should have been according to the estimated figures.



Tunnels grouped according to length



Tunnels grouped according to number and AADT

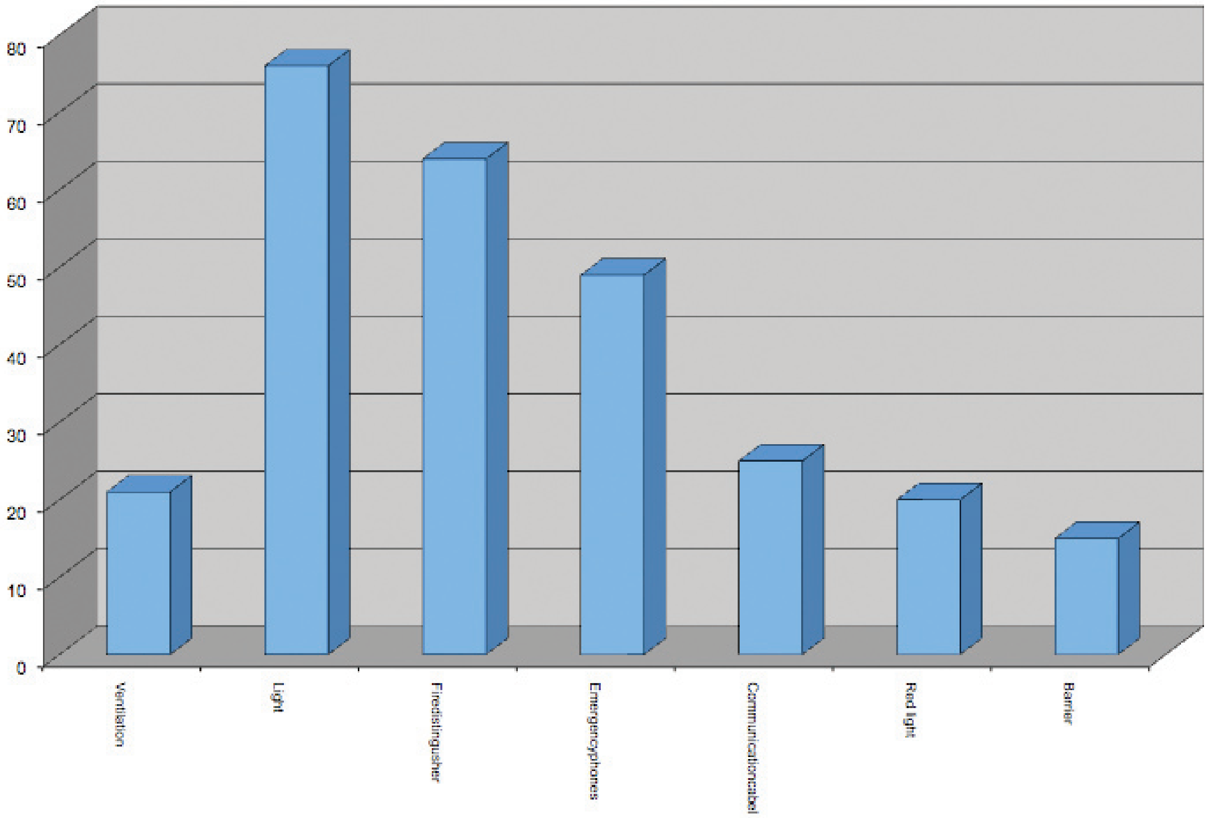
In practice, this means that there is an increasing road maintenance lag with inherent road standard reduction. This situation harms the entire road system, tunnels contain a lot of expensive technical installations this maintenance lag will adversely affect the life cycle of the equipment and thus in fact increase the costs.

OPERATION

The operation and maintenance crews must make sure that the safety in the tunnels during operation is maintained.

This means that the operation and the maintenance work at all times shall safeguard the given safety instructions as requested during the planning and processing of the actual tunnel project. This includes the technical equipment and signal system etc.

Important elements are:
Required standard, that is to decide on classification.
The selection of maintenance-friendly construction- and equipment solutions in the planning phase.
Continuously assess the use of resources, modify to the actual needs.
To strive towards a uniform standard for similar tunnels



Percentage of technical equipment in tunnels on the national road network

of the same type and the same traffic density. This is extremely important on the same stretch of road
The level of competence in the different parts of the organization; project planning, construction and operation.

The operation and maintenance work should basically be performed in accordance with established systematic routines and given time intervals. Operational- or maintenance work performed, either ordinary duties or emergency actions, should be logged in the "AOM" a program for administration, operation and maintenance. The log should confirm standard achievement and any deviations.

Complete safety in view of maintenance
The assessment of the executed safety and maintenance work in the tunnels are closely connected. The applied methods for the work are in both cases based on systematic work over a period of time.

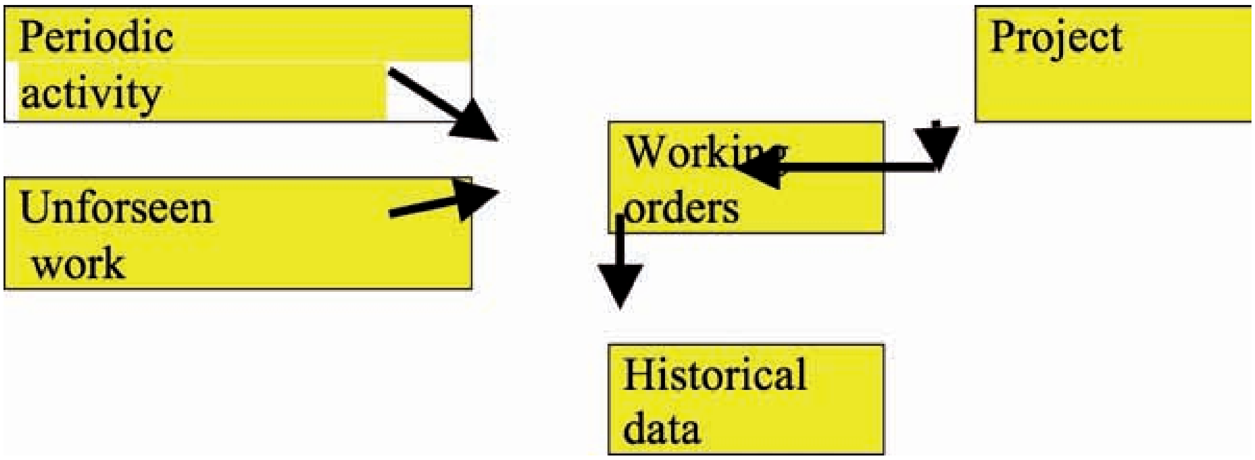
Assessment of safety in road tunnels, whether it concerns preventive or damage reduction activities, will mainly be based on risk analysis in combination with the use of AOM-programs. An important part in tunnel maintenance concerns technical installations that require substantial systematic work.

To undertake work in road tunnels can be strenuous; while in operation the crews are exposed to environmental factors like noise, dust, air pressure, traffic hazards and general stress. Hence, it is difficult to assess the risks versus administrative norms and other marginal values.

The traffic itself is the most stressful environmental aspect the crews are exposed to. Increased attention towards the working environment for the maintenance crews is of utmost importance. Today's temporary limitations on ongoing traffic during maintenance work are too lenient. An escalation in the use of warning signs, temporary fencing and further speed limitations is expected.

In view of above, it is important to increase the knowledge about environmental adverse aspects and how the individual can contribute. Information about the actual HES-conditions will reduce fears for certain kinds of pollution and other environmental aspects in focus by the media. Headlines in the Newspapers may sometimes cause more serious problems than that the actual health aspect the matter may represent.

Important for the safety is the systematic maintenance of the construction elements and the technical equipment; further required is a high level of competence within the maintenance crews.



Above is a process illustration. Detailed instructions are part of a maintenance contract. Template work orders for the periodic activities are downloaded from the AOM program. Observations and registration during the execution is reported back and will eventually be included in the "historical data".

Front page of Handbook with guidelines for HES while working in road tunnels

Through the systematic use of AOM-programs, the experience gained from the historical data will give conclusive knowledge on the selected method and the employed equipment. This knowledge should be constantly assessed and updated.

Exact information on previous decisions and registered outcome is a good basis for future decisions.

Cost efficient maintenance operation requires maintenance-friendly construction- and equipment solutions. The systematic registration and the subsequent exchange of gained experience is good basis for sound decisions.

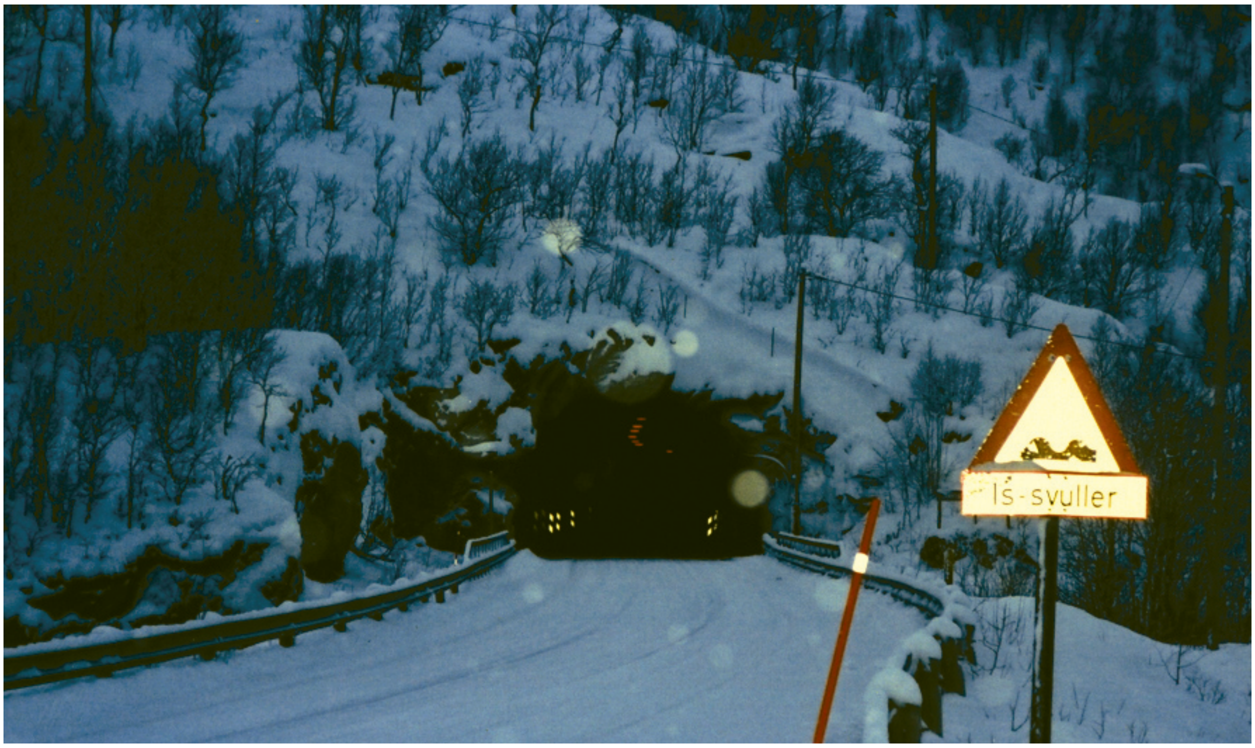
Winter maintenance

Winter maintenance of road tunnels in Nordic countries includes removal of snow, ice, the use of sand and salt on slippery roads, enhanced ventilation and cleaning due to extensive use of studded tires.

Planning starts with the review of established maintenance contracts. These are usually signed for a certain number of years. The system requires tendering to take place well in time to allow the successful contractors necessary time for preparation. A contract will cover a well defined area including roads, bridges and tunnels.

Winter maintenance in tunnels will to a great degree be the necessary work in the transition areas from road to tunnel. Ice problems may be a problem for tunnels where adequate frost insulation is of inferior quality. Graders or tractors shall soonest remove any snow or ice inside the tunnel. This also applies to the portal area, signs, signal systems, any helicopter landing site or technical installation. Detailed contract provisions stipulate frequency etc.

In mountainous areas convoys headed by snow removal machinery are ordinary means of safeguarding road traffic. In climatic transition periods during autumn and spring, maintenance crews and the public must be on alert, the snow and ice in the entrance zone is exposed to melting and freezing during the day and the night respectively.



Any snow in the tunnel should be removed with a grader, plow, blower or tractor.

Efficient winter maintenance is based on the use of high capacity equipment. Access is a prerequisite.

TUNNEL CONSTRUCTION

The profile is defined as:

- Theoretical blasting profile
- Normal profile

A theoretical blasting profile is the expected profile of the tunnel when excavated. The profile defines the roof, the walls and the invert.

A normal profile is the planned tunnel profile (opening) after the installation of rock support, water protection means, any other technical equipment, the road top layers and road surface treatment. In addition, the selected theoretical blasting profile must also sufficiently indicate:
Pumping stations, technical rooms, rooms for the cleaning system, breakdown recess, turning recess, recess for snow plough, area for the lining up of convoy traffic, side areas, round-abouts, ventilators, signs, safety equipment and more.

The plans must also allow space for rock-, frost- and water safety measures.
When planning recesses in the tunnels, it is important that the design sufficiently takes into consideration visibility requirements, traffic regulating measures etc.
Parking/Stop recesses in tunnels are designed with the same standard as ordinary lanes with a width of 3,5 m.

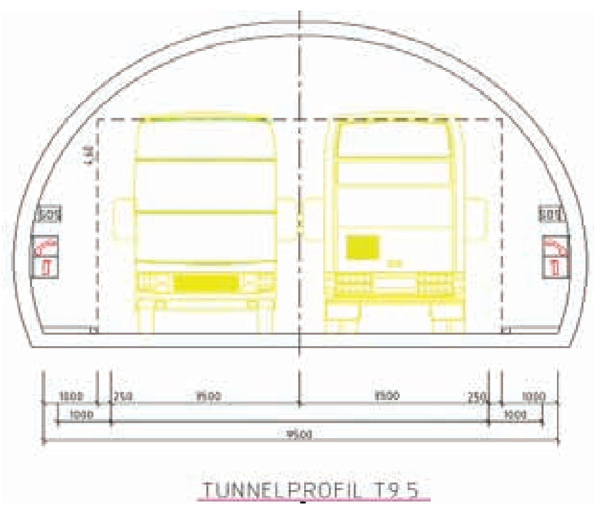
The lower part of the walls shall be designed to withstand a car crash without being damaged. This part of the walls shall be 0,95 and 3,50 metres high in low density and high density traffic tunnels respectively.

Wall surfaces should be easy to clean, while providing a pleasant impression

Concrete elements or bricks of New Jersey type with white cement and aggregates should be used. Advantages achieved are:
The area behind allows for cables and pipes.
Enhanced fire protection.
Smooth and even wall area
Reduced risk for cars thrown back into the road after a collision.
Pleasant impression
Will ease the cleaning and maintain the bright surfaces.

These solutions will require a minimum profile of T-9,5 with 3.5 m driving lanes and 1.25 m shoulder and blasted, straight walls.

During recent years, general approvals have been issued to vehicles with a width of up to 3.4 m (side mirrors included). However, in order to also meet the needs of special transports, a 4,0 meter wide middle section of the tunnel should be 5.0 metres high.



The operation and maintenance require a tunnel profile that allows for necessary technical installations and the use efficient maintenance machinery.

The aim
To secure the road against the downfall of rocks, snow, ice etc.

Types of portals:
Cast in situ reinforced portal of concrete
Cast in situ reinforced portal of sprayed concrete
Portal of concrete element

The planning
Select portal type and length to fit to the local conditions.
Aesthetic design that fits to the surrounding terrain
The following requirements must be met to satisfy operation and maintenance:

Waterproof design
Membranes on all portal structures
Concrete directly against drainage plates which are bolted to the rock
Protection by sand buffer on the cantilever part.
Sidewall and cantilever part to connect to the guard rails

Wet/slippery driving lanes in the portal area
This problem occurs with defects in the portal structure. Defects in the membrane, not just in the portal structure, but also in the transition between the portal and the frost/water protection items, will cause wet or slippery driving lanes.

OUTSIDE AREAS

Accidents happen in tunnel entrance zones. These zones are defined to be from 150 m ahead of the tunnel portal to 100 m behind. The main reasons for the accidents are the changed driving conditions, lights, curves and slippery road surface in the tunnel vicinity.

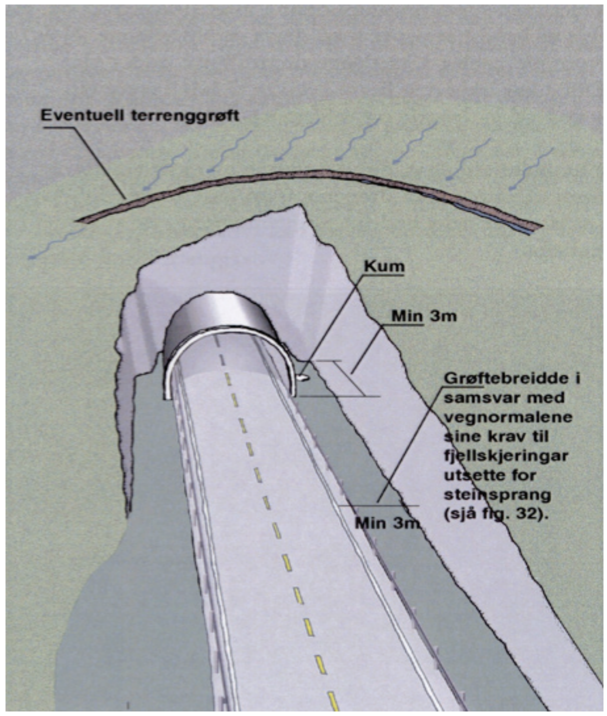
How to secure the entrance zones is seldom mentioned in norms and manuals, and the specific requirements are mostly connected to aesthetic design of portals. The design of the road leading up to the entrance of the tunnel is also surrounded by diffuse requirements and opportunities arise to deviate from the general requirements regarding road shoulder widths, ditches and other secondary areas to reduce investments.

The left side portal is well designed , wheras the right side structure gives the impression of a simple makeshift set up.
Both structures, however is designed to stop incidental blockfall of ice and rocks, water leakages and landslides at the entrance of the tunnel

For many tunnels, mainly low traffic density tunnels, a reduced profile has been used to reduce costs. This means that the most dangerous road section is established where road-users have the most difficult driving conditions.
The length of the portals are often reduced to a minimum, some older tunnels do not have any protection at all

Therefore, one must focus on: The design of the portals, establish sufficiently large ditches,
the necessary side areas, establish ice catchers (steel nets), undertake cautious scaling,
install rock bolts, the necessary fencing for slides, trap walls and landslide fences and/or
jersey/railings

The different items should be considered with a view to maintenance and accessibility.



Above drawing indicates general requirements to the area ahead of a tunnel portal.
The entrance zones are often exposed to slides, earth – ice or boulders from steep hills.

ROCK-, WATER- AND FROST SAFETY MEASURES

The extent of the necessary rock and water safety measures depends to large extent of the quality of the executed rock blasting.

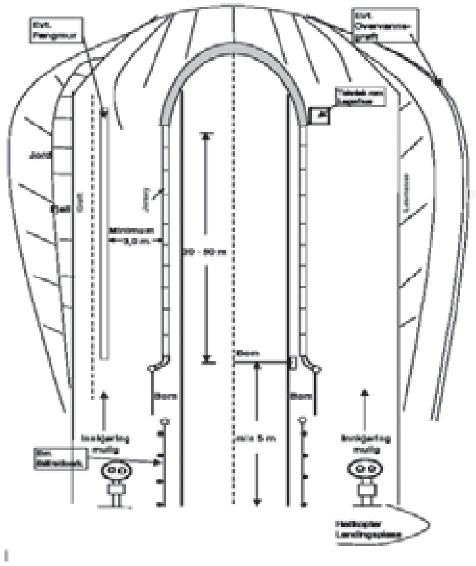
There is a tendency that incorrect drilling and inaccurate blasting leads to great economic consequences, not just increased need for rock support, but also to an increase the operation and maintenance costs.

If the contour blasting is not carried out as carefully as possible, it results in a need for extra clearing and an increase in the amount of bolts which again leads to an increase in the risk of puncturing water access through the bolt holes. This also results in a greater need of water safety measures.

ROCK SUPPORT

The standard rock support methods are: scaling, bolting, rock straps, mesh, sprayed concrete, grouting and concrete. Today temporary support during excavation will be included as part of the permanent support.

Temporary rock support. Intention/aim:	The necessary protection for safe working conditions.
Permanent rock support. Intention/aim:	Safety measures for permanent safe operation of the tunnel. The quality of the temporary and permanent work should be identical. This to be included as a part of the permanent support.
Safety measures after completion: Intention/aim:	Such support is installed only due to previous mistakes, new information or new requirements. (typical situation would be active clay overlooked during the implementation of the actual projects)



The open cut ahead of the tunnel portal requires sufficient space for maintenance to provide traffic safety all year round

WATER AND FROST SAFETY MEASURES

All tunnels should be secured against water ingress. During the cold season it is important to avoid ice-related problems on the road surface, in the tunnel roof or on the walls of the tunnel.

Water ingress is reduced by pregrouting of the rock mass. Remaining water seepage may be stopped by means of waterproof membranes or shielded off.

In low-density traffic tunnels, the use of gates placed at least 150m is a means of solving the frost problems. Under circumstances nothing may be needed. The method to be selected for avoiding frost problems in other tunnels, depends on AADT, the length of the tunnel, the selected tunnel standard and the climatic conditions. The method and selected material must also meet fire protection requirements. An expected lifetime should be at least 50 years.

AVALANCHE PROTECTION STRUCTURES

The structural design these structures takes place in agreement with national standards and designated instructions from the road authorities.

For road-users the protection structures will be observed as tunnels. Architectural design, equipment etc should be planned accordingly. The entrance zone, outside lighting, the railings and other details should be similar to the details in traditional tunnels. Operation and maintenance should meet the ordinary tunnel requirements.

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