1 HEALTH AND SAFETY PRINCIPLES, LAWS AND RESPONSIBILITIES

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1 INTRODUCTION

The Norwegian Labour Inspection Authority is a governmental agency under the direction of the Ministry of Labour and Government Administration. The Labour Inspection Authority has approx. 520 employees and consists of a central office – the Directorate, 11 district offices and 28 local offices throughout the country. The activities of the Labour Inspection are controlled by the Directorate of Labour Inspection, which supervises the Labour Inspection's operating strategy, overall planning and co-operation with central organisations.

The overall objective of the Labour Inspection Authority is to create a sound and healthy work environment for all, with safe and secure employment conditions and a meaningful work for the individual. The Labour Inspection Authority shall be proactive in encouraging enterprises to work systematically towards the achievement of specific goals in order to comply with laws and regulations.

2 STRUCTURE OF THE LEGISLATION

The Working Environment Act was introduced in 1977. It stipulates that occupational health and safety (OHS) is primarily the responsibility of the employer. Based on this Act, as a framework, the Directorate of Labour Inspection is responsible for enforcing the Act with supplementary regulations. The structure of the legislation comprises about one hundred regulations. The most relevant regulations concerning tunnelling work are the following:

- Regulations relating to Systematic Health, Environmental and Safety Activities in Enterprises (Internal Control System);
- Regulations concerning Safety, Health and Work Environment on Construction Sites (Construction Client Regulations or the *'Owner Regulations'*);
- Regulations relating to Rock Work;
- Regulations concerning machinery;
- Regulations concerning the use of technical appliances and equipment.

It is emphasised that the employer must have an overview and knowledge of all relevant regulations of particular importance for the enterprise.

Some of the specific regulations are commented upon below.

2.1 Internal Control System

The concept of the Internal Control System was introduced 1992. The purpose of the regulations is to promote health and a good work environment, and improve safety. The following definition of an internal control system applies:

Systematic measures designed to ensure that the activities of the enterprise are planned, organised, performed and maintained in conformity with requirements laid down in or pursuant to the health, environmental and safety legislation.

The systematic actions shall be documented in writing and described in administrative procedures. Internal control shall be adapted to the nature, activities, risks and size of the enterprise to the extent required, to comply with requirements set out in or pursuant to the health, environmental and safety legislation. Internal control entails that the enterprise in writing has to document the following:

- the enterprise's objectives;
- an overview of the enterprise's organisational set-up, including allocation of responsibilities, duties and authority;
- risk assessment;
- routines to uncover, rectify and prevent breaches of requirements;
- a systematic surveillance and review of the internal control system to ensure that it functions as intended.

The regulations concerning internal control system provide a method for enterprises to comply with existing laws and regulations. The actual acts:
- Working Environment Act,
- Pollution Control Act,
- Acts relating to fire and explosion hazard and fire prevention,
- Product Control Act,
- Civil Defence Act, and
- Act relating to Electrical Installations and Equipment.

All these acts are supervised by different authorities who have to cooperate and coordinate their activities concerning internal control.

2.2 Construction Client Regulations

Construction sites expose workers to high levels of risk. This may be due to the establishing of a temporary production organisation, new management, tight schedules, inadequate coordination, particularly where various subcontractors work simultaneously or in succession. It has therefore been focused on how to improve the coordination between the various parties concerned both at the project preparation stage and when the work is carried out.

An important factor in the regulations is that the client (the project owner) is assigned tasks and responsibilities for ensuring that safety, health and work environment matters are taken into consideration right from the start of the project. The regulations are intended to help in ensuring that the OHS-work is maintained under equal conditions of competition, accordingly plans for this work are required to be included in tender documents and contracts.

One of the most important sections is dealing with a plan for safety, health and work environment. The client or project owner shall ensure that, prior to the mobilisation of a construction site, a plan shall be made that ensures a totally satisfactory work environment.

This plan shall refer to regulations and procedures relevant for different tasks. In order to ensure that relevant factors are taken into consideration in connection with tenders and contracts, it is very important to include requirements regarding measures or working methods that may have time or cost impact during the execution of the project. The main sections of such a plan may e.g. contain the following:
- relevant data for the organisation of the construction site including responsibility and distribution of tasks;
- a drawing showing the physical arrangement of the construction site, with particular emphasis on factors like construction cleanliness and materials handling;
- a schedule showing in detail where and when the different tasks are to be carried out and how much time has been allocated to each of them;
- a description of particularly dangerous tasks and how they shall be carried out;
- descriptions of how e.g. personnel rooms, access and transport roads, lighting etc shall be organised and solved;
- requirements regarding the contractors that are to carry out construction work;
- information routines;
- routines for dealing with deviations.

See also paper no.5 in this publication

2.3 Rock Work Regulations

The Rock Work Regulations came into force 1998 and is a revision and combination of six older regulations. It is adapted to the EU-directive 92/104/EEC on the minimum requirements for improving the safety and health protection of workers in surface and underground mineral-extracting industries and the ILO Convention no. 176 and Recommendation no. 183 concerning safety and health in mines.

The regulations apply to all types of rock works, on surface and underground. Rock works includes i.a. drilling, blasting or other types of fragmentation, scaling and all types of stabilisation work, loading and transportation. This means that both mines and quarries as well as tunnelling work and other construction work in rock come in under the regulations.

Under section 4, comments follow on some of the most important requirements in the Rock Work Regulations.

2.4 Blasting Regulations

Specific regulations relating to blasting, i.e. charging, initiation and handling of explosives are handled by the Directorate for Civil Defence and Emergency Planning (dsb previously called DBE)

This directorate deals with matters falling under the following acts:
- Act relating to Fire and Explosion Prevention
- Act on Supervision of Electrical Installations and Electrical Equipment
- Act on Control of Products and Consumer Services and from June 14. 2002
- Act relating to protection against fires, explosions and accidents with dangerous goods and abut the duties of the fire squads (Fire, explosions and disaster prevention act) and
- Regulations relating to the handling of dangerous goods. (Regulations on Explosives)

See also paper no. 3 in this publication.

3 GOAL-ORIENTED LEGISLATION

The traditional regulatory strategy in Norway, usually called prescriptive regulation, was to specify detailed rules for those who create risks, in particular employers. This type of regulation prescribes precise, detailed steps to be taken by individuals or organisations, leaving little or no discretion for deviation.

During the past two decades there has been a shift away from this type of strategy towards one that aims on certain safety goals for the direct risk control functions. In the literature, this type of regulation has several names, i.a. goal-oriented legislation. The goal-oriented legislation specifies what must be regulated within the organisation and how the authorities outside will check that this has taken place. By offering rules as a framework, formulated as goals, it is in principle the responsibility of the organisation to decide how to best achieve the safety goals.

Modern regulations do not put detailed requirements in the paragraph text. The level of a requirement is normally given in the guidelines to the respective paragraph, as examples of actions and solutions or references to standards, handbooks, practise, etc. This means that the level of a requirement is not permanent. In step with the technical and social development, the level of a requirement may increase without any need to change the text of the paragraph. In other words, the authorities do not want to hinder the technical development.

Fewer and better regulations were a motto for the 1990’s. During the last years all the regulations, for which the Directorate of Labour Inspection is responsible, have been reviewed in order to make them more concise and easier to understand.

4 IMPORTANT REQUIREMENTS IN «REGULATIONS RELATING TO HEALTH AND SAFETY WITHIN ROCK WORK» (REGULATIONS RELATING TO ROCK WORK)

Below are comments on some of the most important requirements, which have improved health and safety in Norwegian tunnelling during the last five years.

4.1 Risk assessment

The planning of a blast requires a risk assessment and the mapping of potential accident aspects.

4.2 Geological investigations

An assessment of the geological situation is an important part of the required plans, consequently geological investigations are necessary. See also paper no. 4 'Geological hazards – causes, effects and prevention' in this publication.

4.3 Diesel exhaust underground

The last few years, extensive attention has been given to health damage caused by diesel exhaust in tunnels and mines. The aim of an ongoing project is to clarify the health-related consequences of using diesel powered equipment underground and to propose measures that reduce the risks.

For the time being the regulations have no requirements on maximum sulphur content in diesel fuel used underground. However in the guidance to paragraph no.14 there is a recommendation to use the best quality of low-sulphur diesel fuel available on the market and to equip diesel engines with some type of cleaning device for the waste gases, e.g. particle filters. One will find some further info in paper no. 9 'Diesel Underground, project results and recommendations' in this publication

4.4 ‘Danger zone’

To improve health and safety during the drilling sequence there is a requirement in paragraph no. 20 in the Rock Work Regulations stating that nobody is allowed to stay within the ‘danger zone’ while drilling (blast holes and other drilling) is going on. The ‘danger zone’ is defined as the area between the supports of the booms to the drilling jumbo and the tunnel face. This requirement has been thoroughly discussed with the contractors as it effectively forbids to carry out the charging of explosives when the production drilling is going on. There are many reasons to forbid people to stay in the danger zone i.a. the very high noise level, the risk for rock falls and the risk to drill into explosives (from the previous round) that have not detonated. One will find some further info in paper no. 8 'Automatic charging of emulsion explosives etc' in this publication

4.5 Ventilation

It is said that: "The one who does not undertake any measurements does not know anything". Therefore paragraph no. 24 requires that the employer shall undertake regular measurements in order to detect the amount and concentration of hazardous gases and particles. Paragraph no. 25 states that all workplaces underground shall be satisfactorily ventilated so that the concentration of hazardous gases and dust in the air, which is inhaled, will be as low as possible and shall not exceed the Norwegian list of Occupational Exposure Limits (OEL). (frequently used is also the identical term Treshold Limit Value - TLV)

The Norwegian OELs are called "administrative norms for pollution in the working atmosphere" and are based on technical and economical factors in addition to the toxicological and medical documentation. It is stressed that the risk of health effects not necessarily is entirely avoided even if the exposure is below the OEL. It is therefore recommended that the exposure should be as far as possible below the limit. The OELs are guidelines that will be legally binding if used in regulations from the Labour Inspection, or in orders issued by the Labour Inspection to an employer.

In tunnelling the most important and problematic substance is normally nitrogen dioxide. The Norwegian OEL-value for NO_2 is 2 ppm. This is a ceiling-value and means that the concentration should not be exceeded during any time of the working exposure. In most cases carbon monoxide, CO, is no problem. The OEL-value for CO is 25 ppm and is a time-weighted average concentration for an 8-hour workday. Short-term exposures should not exceed 100 ppm. Thus it is up to the employer to choose an adequate ventilation system depending on i.a. type of explosives, the amount of engines, the fuel quality and whether diesel engines used are equipped with some type of cleaning device for waste gases.

One will find some further info in paper no. 7 'Development in ventilation methods' in this publication.

4.6 Fire prevention
A fire in a motor vehicle or construction machinery develops quickly and, depending on the location of the fire, it may not be possible to bypass the fire in a tunnel drive with only one way out. Paragraph no. 27 therefore requires some type of a rescue chamber (safety container) if there is only one way out. The Norwegian Tunnelling Society (NFF) has prepared guidelines regarding design, construction, size, necessary equipment, maintenance and use of such containers. See also paper no. 14 'Safety container' in this publication.

4.7 Personnel underground
Paragraph no. 30 requires a system which makes it possible to know, at every moment, the name of all persons staying under ground and the possible location. This is very important in case of an accident or a fire. It has always been a problem to control the number of persons who stay underground at every moment. Especially today as there is a lot of ‘back front’ work going on parallel to the tunnel driving. In Norway some new systems have been developed based on micro-waves. This means that persons wearing a special "tag" automatically will be registered when they move into or out of the tunnel. The system can also give an alarm if not authorized persons without such "tag" try to enter the tunnel. Further info will be found in paper no. 11 'Electronic access monitoring' in this publication.

5 CONCLUDING REMARKS
Mining and tunnelling works have always been recognised as having hard and tough working conditions. However, conditions can be improved by:
- Proper risk assessment,
- Suitable documentation,
- Functional requirements encouraging more extensive use of available guidelines and handbooks.

Statistics show that more than 90% of all serious accidents happens because one has:
- not implemented preventive actions
- not obtained the required permits
- not carried out the necessary training.

Even considering all the efforts the last few years, it is therefore still a large potential for improvement.

Typical hydropower station during construction

2 UNDERGROUND WORK ENVIRONMENT, CHEMICAL AND PHYSICAL – CAUSES, EFFECTS AND PREVENTION

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Abstract
The general tendency in Norwegian tunnelling and other underground construction works during the last 10-15 years is improved safety whereas improved health could not be observed. The health aspect is a challenge that must be given increased attention.

All types of rock blasting works, including tunnelling and mining, have a high injury frequency rate with a high severity factor.

Demands for reducing construction times increase the production intensity. The amount of air pollutants produced per time unit is increasing as well. Counter-measures put into effect have positively influenced the exposure and safety situation for the workers.

Examples are new ventilation methods, better blasting agents and technology, cleaner diesel engines and fuels, general acceptance of the importance of systematic health and safety work. There are still challenges concerning the work environment, especially the chemical and physical factors such as mineral dust, gases, noise, vibrations, lighting etc. Today much attention is given to health damage caused by diesel waste gas (exhaust), but also the exposure to mineral dust is in focus.

1 INTRODUCTION

Tunnelling, mining and other underground works have always been seen as a 'tough' trade. Dust, gases from diesel and blasting, soot, oil mist, noise and vibration, radon and radon-daughters, different chemicals, rock falls, temperature and air humidity, heavy and uncomfortable working positions with arms over the head, reduced light and visibility, danger of explosion, traffic accidents etc are typical, and put a heavy burden on the workers. Increased mechanisation and automation have reduced the physical loads, but have increased the psychological stress.

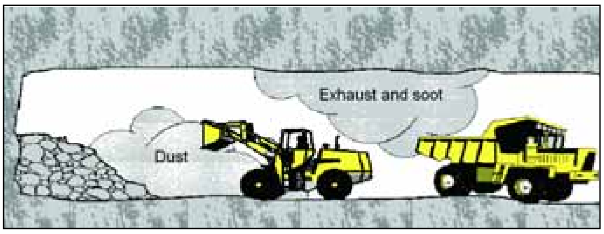

Figure 1. Exposure to pollutants

Injuries from rock works can be fatal (rock-falls, drilling into remaining explosives, etc). The accidents that cause injuries to personnel may cause damage to material or the external environment. All such losses are undesirable. Most accidents, however, causing injuries to personnel and/or material damage can be prevented.

Many examples can be found where companies have achieved remarkable improvements in their Health & Safety work, including reduced accident rates and simultaneously experienced good economic returns.

The environmental preconditions and requirements for tunnelling, mining and other rock works are continuously made stricter. Regulations issued during the recent years increasingly set stricter targets for the general standard of the work environment as well as the external environment, stricter administrative norms for allowable concentrations of pollutants in the air, and more rigorous rules and regulations linked to procedures, methods and equipment. Simultaneously the mass-media, environmentalists, action groups and others continually focus on factors which may influence neighbourhood and environment.

Transfer of knowledge and the understanding of new information are crucial factors for the development of a better work environment aimed at improving the health situation. This applies to environmental loads linked to blasting/explosives, fuel/diesel oil, rock types/mineralogy, dust, gas, chemicals, noise, water, temperature, radioactive radiation and others. Effects resulting from combinations of materials that influence people and the environment must be put into focus, and relevant criteria and procedures for controlling/monitoring releases to air, soil and water must be established. This also includes grouting materials. These must be safe to handle and use under the prevailing conditions, that includes possible contamination.

2 EXPERIENCE WITH THE WORK ENVIRONMENT

Underground excavation has a high and steadily increasing degree of mechanisation. The capacity of available equipment increases, new technology or improved methods are continually introduced. In the context of such development it is important to emphasise the a necessary balance and measures being taken for the work environment. Otherwise the commercial benefits of technical development may be outbalanced by negative side-effects.

Today's challenge with respect to preventing health injuries from rock-blasting activities is about dealing with existing problems due to noise, mineral dust and vibration. Those problems cause 3 out of 4 work illnesses in Norway.

The work environment is usually described as physical and chemical environmental factors on one side and psychical and social factors on the other. There can be considerable differences as to how individual employees experience their own work situation and work environment. The experienced risk is often different from the actual risk.

The general development in tunnelling over the last decades has in many ways positively affected Health, Safety and Environment (HSE). This includes increased interest and improved attitude and motivation for the HSE-work. The understanding of the relation between production work and HSE has improved. Further, the legal responsibility of top level management has been made clearer and more transparent.

Improved explosives, blasting agents and blasting techniques, more effective watering of the muck-pile, increased use of electric energy, cleaner engines and fuel, more systematic service and maintenance of equipment and roadway, more effective ventilation methods, are all useful factors to improve the air quality underground. These efforts also affect productivity and economy in a positive way. Training and control functions are improved. A motivated and determined management is necessary for this development.
Analyses of sick leave and rehabilitation efforts, have in recent years improved the understanding of health problems and methods to reduce the problems. Measurements of work hygiene and product development in relation to protective equipment are important key factors in the work aimed at preventing illness at work and personal injuries.

3 WORK ENVIRONMENT AND MEASURES

The stimulation to a greater degree of technical and medical co-operation aimed at more purposeful and cost-saving supervision and inspection procedures, both regarding prevention technique and health services, will contribute to an improvement of the work environment in line with the society's general expectations.

Because of the demand for reducing construction time for tunnel projects, dealt with by increased mechanisation and productivity, the amount of air pollutants produced per time unit is increasing. If the right measures are not taken, the air quality underground may be dramatically worsened and the workers highly exposed to a variety of airborne substances.

With reference to the work environment generally, the chemical and physical factors such as dust, gas, noise, vibrations, lighting are very similar in the construction and mining industries. On the other hand, conditions related to psychological pressure or stress can be rather more dominating in construction activities (tunnelling) than is usually the case in mining. This has been confirmed in discussions with employees with experience from both the construction and the mining industry.

Tight construction schedules cause an increasing amount of work to be executed simultaneously behind the face. This may worsen the air quality and the work environment related to residual materials significantly. When bolt hole drilling for permanent rock support, concrete- and carpentry work, cleaning of footings, infilling of roadway sub-base, trench digging, piping works, drainage etc take place concurrently with excavation activities, it is obvious that reduced air quality and worsened general safety may easily result. Particularly, activity in the completion phase can cause a 'pile-up' of site clearance work, including the removal of rubbish, literally giving a 'messy' work situation.

The work environment and air quality at the tunnel face is only slightly affected by increased activity behind the face. To obtain an acceptable work environment for the tunnel as a whole, the working patterns in the tunnel should therefore attempt to eliminate or even out the environmentally harmful activities over the building period as a whole, and also over the shifts during the day.

4 CHEMICAL AND PHYSICAL PARAMETERS

4.1 Blasting and explosive gases

During blasting operations, workers in tunnelling, like in mining, were for many years exposed to unacceptable concentrations of gases when passing through a smoke plug after a blast. In mining this is today a minor problem since blasting takes place at shift changes or at ends of shifts when the miners are out of the mine or far away from the blasting area.

Emulsion explosives in tunnelling have been in commercial use in Norway since 1996. Since 1993, technical investigations on blasting fumes, dust, smoke and visibility and other factors concerning the slurry and emulsion techniques compared with ANFO have been carried out.

Today emulsion explosives dominate. The liquid is transported directly to the site, pumped into the drilled holes and subsequently sensitised

The work environment (air quality) at the face and behind is highly improved because of much lower concentration of especially nitrogen dioxide (NO_2), but also carbon monoxide (CO). Less dust, both total and respirable, is produced. This gives lower airborne smoke and dust concentrations and increases the visibility. Using liquids give less spill, waste and pollution to the water in the tunnel, and the need for transport and storing of explosives is reduced.

The health risk associated with explosive gases in tunnelling is clearly reduced in recent years. The blow-exhaust-combination ventilation method that was introduced in Norwegian tunnelling in the 1986/87 was adapted to the use of ANFO. Today well sized ducts and the blow method dominate.

Natural occurring gases can cause risks or health problems, thus the inherent hazards have to be continuously focused. Methane is normally a coal mine problem. But like other natural gases, like radon and hydrogen sulphide, it may be met also in tunnelling. High ventilation intensity will reduce risks for health hazards.

4.2 Diesel exhaust

Since heavier wheel-going diesel machines were introduced in mines and tunnels, exposure to gases and particles have been among the dominating burdens in these industries. For a long period of time, the focus was exclusively on fuel consumption and waste gas quantity from diesel engines. During the 1990's, increasingly more attention was directed to pollution and air quality for underground rockwork. It was acknowledged that conditions connected to waste gas/exhaust, particle pollution, ventilation, flushing of muck piles, the quality of roadway, etc. have a decisive influence on the working conditions, both on and behind the face. This must be taken into consideration when organising the plant and determining operation arrangements.

Today, however, as 10 years ago, questions are still asked regarding threshold limit values (TLV), marginal values, exposure/emission, measuring methods (what is to be measured, when, and how?). We are looking to find one (or a few) exposure indicators that are simple to measure using effective techniques, such as light instruments with direct indication. This applies to the work environment as well as the external environment. So far, though, one has not succeeded in finding such a criteria or proposals for such.

4.3 Ionising radiation

Employees underground is on the average that group of workers in Norway exposed to the highest dose of ionising radiation. This is caused by the presence of radioactive components in the rocks or the joints, which i.a.may emit radon and radon-daughters, and to some extent, thoron and thoron-daughters.

Normally, radiation is not a problem in Norwegian tunnelling, because of the high ventilation volume applied for other reasons (blasting, loading and transportation). If the ventilation is reduced or stopped, however, the concentration of radon can increase rapidly to high levels. When starting the ventilation again, the concentration will after a few hours return to the background level.

4.4 Particle pollution

In spite of the introduction of dust-damping efforts and ventilation, particle pollution (mineral dust, organic particles like soot and oil mist) is a dominating air-polluting environmental factor in rock-blasting work. Investigations show occurrences of illness from dust in the lungs (reduced lung function and lung diseases, among others silicosis). Since the early 1970's, testing and documentation of dust and other air pollutant have been carried out. This includes sampling of dust, with measurements of quartz content and types of particles. The objectives have been both a documentation of the level of exposure to dust for individual workers, as well as determination of the background level in different work situations and areas.

Investigations show that the threshold limit values (TLV) are reached more frequently in tunnelling than in mining. This is especially linked to differences in the quartz content in the dust, but also to the fact that the work intensity in tunnelling operations often are higher than in mining.

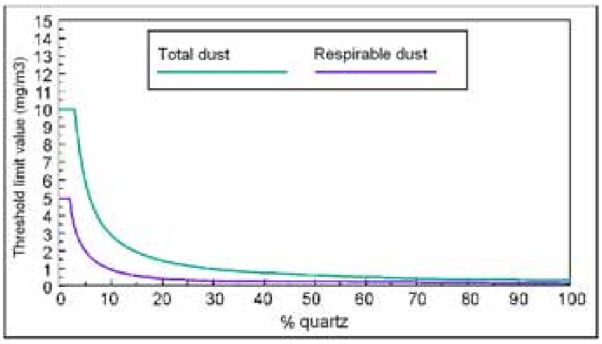

Figure 2. The relation between TLV and the quartz content in the dust.

The content of alpha-quartz in the dust from the tunnels varies between 0 % to more than 50 %. Investigations indicate that the danger of silicosis must still be regarded as real in a number of tunnelling situations. Therefore it is necessary to use available knowledge and information, to check and apply preventative efforts together with regular and proper health supervision of the employees. The TLV for rock dust depends on the quartz content as shown in Fig. 2.

4.5 Noise

Noise is probably the individual factor that causes most injuries at work. In the tunnelling and mining hardly any 50- to 60-year old worker within rock blasting and underground working has normal hearing. The great majority is more or less hearing-impaired.

4.6 Whole body vibration and lighting

Whole body vibration and lighting (poor light) are important, but often neglected environmental factors, which can cause personal injury and accidents. In particular rubber-wheel mounted production equipment (loading machines, load and carry trucks) combined with poor roadways/foundations can cause heavy whole-body vibrations.

4.7 Tunnelling Boring Machines (TBM)

The first regular tunnel boring in Norway started in 1972. Since then some 320 km has been bored. Use of TBMs has, compared with conventional drill & blast tunnelling reduced or completely eliminated environmental pressures like blasting fumes, diesel exhaust, block-falls, but has at the same time resulted in increased pressures elsewhere.

Questionnaires show that TBM operators perceive the following environmental factors as most onerous: noise, mineral dust, vibrations, heat (when changing cutters), repetitive work, and ergonomic pressures. A clear majority fear health risk on account of long-term effects of dust, noise and vibration more than the risk of acute, mechanical character or pressure injuries.

There is still a potential for improvements to be obtained with relatively small adjustments and modification of current operating methods. This relates in particular to suppression of mineral dust, noise and ventilation.

4.8 Long tunnels and ventilation

In 1995 the longest road tunnel in the world, the Lærdal tunnel, was commenced, with 24.5 km length. The tunnel was completed in year 2000. It was a great challenge to the efforts towards health, environment and safety, and especially concerning the choice of an optimal ventilation method.

Some years ago high, exposure of blasting fumes in tunnelling was highlighted by The Directorate of Labour Inspection. As a consequence attention was drawn towards the application of the two-way ventilation methods. This could be implemented either by the single- or the double-tube technique, supplemented by the use of mobile fan systems. Both versions have advantages and disadvantages. The length of the tunnel matters.

In the Lærdal tunnel the single-tube versions were developed further, by means of a bypass air system for surface fans, mobile fans and auxiliary fans that reduced frictional losses through these fans. Both the single- and double-tube systems were used.

It is interesting to notice that during the 5 years of the excavation of the tunnel, more than three times as much air (expressed in tons) as rock has been transported through the tunnel. A similar observation can be made in nearly all tunnels and even mines in Norway.

5 DEVELOPMENTS AND POSSIBLE FUTURE PROBLEM AREAS

In the following a summary is given of a number of other relationships which are important, or will become of importance for HSE work in the time to come:

- HSE work must be become an activity with equal priority as planning, progress and economy.
- HSE 'Safety Delegates' are an important and positive resource. They must be better utilised.
- More information on the use, service value and limitations for various types of protective equipment, e.g. personal protective equipment against gases, dust, noise.
- Reduction in administrative norms, e.g. for nitrogen dioxide and soot particles. Greater weighting of additive and synergistic effects with the introduction and use of the summation formula for consideration of air quality underground.
- Methods for control, monitoring and sampling vary greatly in frequency, content and quality both relating to medical and exposure research studies. Gas and dust monitoring instruments give different results with parallel measurements. Different types of spirometers/lung function meters may give different volumes with poor quality assurance and lack of meaningful calibration. Different procedures for spirometry – standing or sitting – will give different results, as may different software for the calculation of results from lung function measurements. Equipment and procedures must be homogenous and harmonised, including calibration routines for both medical and technical monitoring.
- Improved air quality and visibility, improved road surfaces and faster cars lead to generally increased speed during tunnelling, and increased risk for traffic accidents.
- During excavation ventilation is a crucial factor. Ventilation is expensive, and care must be taken to choose a solution that gives the maximum utilisation for every cubic metre of air that is brought in. It is important that savings are not attempted on the ventilation, but over-complex ventilation solutions can also give other effects than those desired.
- Concrete spraying and grouting work are very demanding work operations underground. Use of protective equipment and optimisation of operations must be improved.

The industry is confronted with many difficult and challenging HSE tasks linked to underground work. However, the industry has competent workers and leaders who will ensure that the laws and regulations required for conforming to the environmental standard will be complied with through a collective and responsible effort.

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3. FIRES AND EXPLOSIONS – CAUSES, EFFECTS AND PREVENTION

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1 REGULATIONS REQUIRE INTERNAL CONTROL

Modern tunnelling requires competent planning to achieve maximum safety for the tunnel workers and, at the same time, to maintain production efficiency with the chosen working methods. All safety aspects must be addressed during the early stage of the planning process.

In Norway the authorities have introduced a system of regulations which gives a great deal of freedom for the project owner and the contractor to choose suitable solutions concerning health and safety. This system called internal control is based upon the principle of targeting ***'as low level of risk as practicable possible'***.

This method, called **ALARP**, is based on risk assessments related to specified acceptance levels. The contractor is given the responsibility for identifying and assessing the risk elements, and has to describe and document the complete internal control system in a written report.

2 SOURCES OF FIRES AND EXPLOSIONS

In underground operations sources of fire could be flammable goods, explosives and gas. Prevention of all kinds of risk is a major objective in safety planning. Preparation for and establishing emergency procedures to handle incidents or accidents is another part of the safety planning.

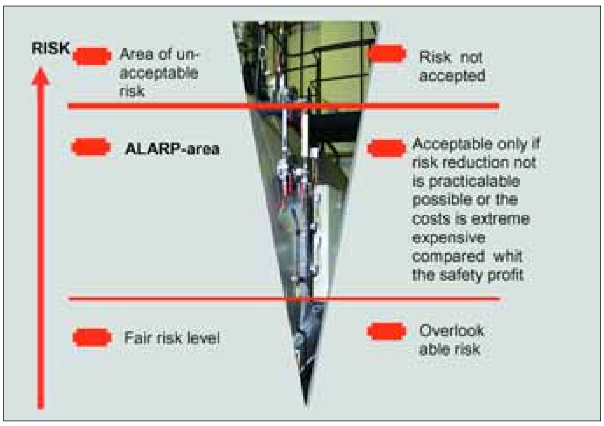

Fig. 1: Principle of ALARP

Fire can be caused if flammable material is present. In tunnelling, flammable material will be found in drilling jumbos, loading rigs, dumpers, electrical equipment of all kinds, temporary maintenance workshops underground, ventilation ducts and more. Some explosives are flammable; others ignite under high temperature only. Explosives are dangerous goods though and represent a major risk in case of fire. Detonators become unstable already from a temperature of 100°C.

Unwanted explosions may occur due to fire in the surroundings. Other sources can be sudden impacts, e.g. from falling objects or rock fragments from walls and roof. Transient currents from electrical equipment and lightning can initiate detonators. If these are primed with explosives and/or stored together with other explosives, there is a possibility of explosion with potential severe consequences.

3 STORAGE AND HANDLING OF EXPLOSIVES

The main objective in safe behaviour and handling of explosives is to keep primary explosives, such as detonators and fuses, at safe distance from other explosives.

New regulations regarding storage of explosives came into force 1. January 2000. These regulations give specific instruction as to:

- Where to place the storage
- How to build the storage
- How to run the storage
- What type of explosives can be stored in the same place
- The trustworthiness of the responsible person
- The skill and age of the persons handling explosives
- How to rebuild/repair the storage in a safe way

4 RISK ASSESSMENTS AND ACCEPTABLE RISK LEVELS

The alternative to demonstrate compliance with the Q/D-tables (Safe distance related to quantity of explosives, see also appendice 'Definitions and explanations') is the use of risk assessment to show that the applied storage meets the safety standard specified in the regulations. The regulations state that the applicant must do a quantitative risk assessment to show that the storage meets the requirements. The regulations give criteria both for acceptable 'individual risk' as well as 'group risk'.

While developing risk criteria, it had to be established certain 'risk levels' assumed acceptable to the society at large. It was also necessary to establish acceptance criteria for both individual and group risk.

Individual risk means the risk a person have to tolerate from e.g. a specific storage of explosives, and is expressed as follows:

$$r_i = P_E \times \rho \times \lambda$$

where:
r_i = Individual risk
P_E = Probability of detonation involving the contents of a storage yr^{-1}
ρ = Presence factor that is the maximum frequency of presence of a person in an exposed object
λ = Lethality, as a function: f(blast, debris)

What makes risks acceptable for a person, are, amongst other factors, his involvement in the activity; whether the person has any benefit from the activity and who is responsible for the safety. To deal with this matter the persons have to be divided into three different categories:

Category 1: Directly involved
Category 2: Not directly involved
Category 3: Not involved

To find what would be an acceptable risk for Category 3 one can e.g. count the number of children that die from accidents in one year, and then establish the probability for a child to die from an accident. Or one can take the number of fatalities from different kinds of accidents in the country and find the rate that society does not react upon. Thereby, one gets an accident level that society actually accepts.

Taking into account that storage of explosives is a necessary element in the utilisation of a product that has certain dangerous properties, it is natural to compare the acceptance criteria for such storage to the level that is otherwise accepted in society.

When doing this it was found that in Norway a risk on 2×10^{-7} yr^{-1} could be acceptable for those not involved (Category 3). Those partly involved should have to tolerate a risk ten times higher then those not involved, and those involved should have to tolerate even ten times more then those partly involved. This gives acceptance levels for individual risk from storage of explosives as follows:
Category 1: 2×10^{-5} yr^{-1}
Category 2: 2×10^{-6} yr^{-1}
Category 3: 2×10^{-7} yr^{-1}
Group risk or collective risk is the risk persons in the neighbourhood of an explosive storage has to tolerate, or in other words, the group risk (RG) is the totalised individual risks for the specific storage:

$$R_G = P_E \times r \times \lambda \times \nu$$

where:
R_G = Group risk
P_E = Probability of detonation involving the contents of a storage yr^{-1}
ρ = Presence factor that is the maximum frequency of presence of persons in exposed objects
λ = Lethality, as a function: f(blast, debris)
ν = Number of persons exposed

When establishing an acceptance criteria for group risk one have to consider the maximum expected number of dead persons from a detonation in the storage. If the number of fatalities increases, the reactions from society increase even more. To allow for this effect, when calculating the expected risk one has to use the following equation:
Expected risk = incident frequency × consequences × aversion factor

In Norway, the aversion factors ϕ is taken as $2^{(Fn/5)}$ where Fn is the fatality number. The aversion factor starts at 1 for 0 expected fatalities and flattens off at 16 when the expected numbers of fatalities reach 25; beyond this number of fatalities the reaction from society will not increase. A disaster is a disaster.

The acceptance levels for group risk given in the regulation are:

Category 1, 2 and 3	: 3×10^{-4} yr^{-1}
Category 2 and 3	: 2×10^{-4} yr^{-1}
Category 3	: 1×10^{-4} yr^{-1}

These acceptance criteria are including the aversion factor.

A quantitative risk assessment includes the expected accident frequency, the lethality for exposed persons, expected presence in different situations and acceptance criteria. In the regulations the criteria for acceptable risk reflects the risks that society accept in other areas, taken into account the storage of explosives' part of GDP (Gross Domestic Product). Up to a certain number the response from society regarding one accident compared to another accident increases more than the difference between the numbers of fatalities. To account for the accepted risk one must multiply the expected number of fatalities with an aversion factor and then with the incident frequency.

5 DRILLING AND CHARGING

Drilling blast holes and charging explosives simultaneously at the work face is now prohibited, hence no source to accidents, but there are still some incidents.

Safe ignition of all blast holes is important also from a safety point of view. Remaining explosives from misfires in the ignition pattern, or otherwise remaining unexploded in the rock or muck pile, can be a large risk. Firstly, for the people involved in loading of the muck pile and subsequently during the other steps of muck handling. Remaining explosives in blast holes in the invert are a safety problem especially if the cross section has to be enlarged with a lower bench.

In most cases non-electrical detonators are used in tunnelling. The wide use of electricity and electrical components are no longer the source of unwanted ignition.

If electric detonators should be used, detonators with very low sensitivity to electric current (HU) intended for the use in tunnelling must be supplied. The drilling equipment must meet a certain technical standard to avoid electrical faults.

6 FIRES

If exposed to flammables, any hot surface may be a source of ignition, e.g. electrical elements, lighting equipment or hot parts of engines. An oil leakage towards a hot surface or a broken glass on a heavy searchlight can start a fire.

Fire in a tunnel or an underground plant without ventilation will take many hours to overcome. If the staff shall be rescued they must be supplied with fresh air. A self-rescuer gives protection for a limited time. Safety containers equipped with breathing equipment and air bottles can serve as safe haven to trapped crew for at last 6 hours. Each individual needs from 10 to 100 litre air pr minute depending on physical activity. The air station must be dimensioned so that everyone connected can get enough air for the period they are in need of extra air.

The fire gases will reduce the visibility in a tunnel. Therefore it is very difficult to get in or out of the tunnel system during the time gases occur. A fire in a drilling jumbo can last for hours.

In cases of explosion in a tunnel, the pressure wave could destroy most of the inventory, such as ventilation tubes, cars and all kinds of loose supplies. Being hit by loose fragments is probably the most frequent injury cause. The pressure wave will destroy almost everything in the tunnel exit. Facilities for people outside the tunnel must be placed away from the blast effect sector in front of the tunnel.

7 EXPLOSIONS

The maximum amount of explosives allowed to be stored in a tunnel system is 3000 kg, divided into 2 equal units. An explosion in one unit must not ignite the other one. In case of emergency during use of a charging truck, the charging operation shall allow a fast evacuation from the work face. If explosives are burning, one shall not try to extinguish, but evacuate the area immediately. Burning explosives rapidly become very sensitive and may explode.

New technology, based on mixing raw material on site, gives more safe solutions.

Today there is - detonators and primers excepted - no need for ordinary explosives for tunnel blasting. Bulk systems exist, from ANFO and slurry to site sensitised emulsions.

Emulsions give less smoke, less gases, improved visibility and work environment.

Through the introduction of the bulk systems the risk for fires or unplanned explosions has decreased significantly.

Figure 2. Example of damage outside a tunnel after an explosion inside

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Specialist waterproofing company

Ownership
Giertsen Tunnel AS is a privately owned, limited company based in Bergen, Norway. We offer our own patended waterproofing solutions to tunnels and rock caverns world wide. The company is a part of the Giertsen Group, established in 1875.

Installation of WG Tunnel Sealing System in rock cavern used for storage.

Staff
Giertsen Tunnel AS has a staff of profes-sional employies that have worked more than 20 years in the field of waterproofing.

Main products
WG Tunnel Sealing System (WGTS) is a patended system, which in an effective and inexpensive way gives a permanent sealing of humid rock walls and ceilings.

The WGTS system is a complete package of humidity sealing of any rock surface in rock caverns, shafts and adit tunnels. The systems is offered complete installed or with use of local labour supervised by our specialists.

Combined with dehumidifiers, the system provides an ideal enviroment for corrosion-free storage of sensitive equipment etc. for both civil and military purposes.

The WGTS will give you complete humidity control year round and low energy cost out range the alternative solutions.

The WGTS system can be used for
- Hydro Electric Power Plants
- Public Fresh Water Supply
- Sports Centre
- Military
- Storage room
- Civil Defence Shelter
- Technical installations etc.

WG Tunnel Arch (WGTA) is a complete system for water leakage, humidity protection and frost insulation of road tunnels. WGTA is designed for low traffic tunnels, and is known as the most cost efficient waterproofing system in road tunnels

Installation of WG Tunnel Arch in the Rotsethorntunnel, Norway.

References
This systems have been used on projects in: Zimbabwe, Nepal, Pakistan, Sweden, Italy, South Korea, Switzerland, Singapore, Finland, Iceland and Norway.

Other products
WG Membranes used for waterproofing of tunnels. We have membranes in PVC, HDPE, LDPE, FPO and PP.

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4 GEOLOGICAL HAZARDS – CAUSES, EFFECTS AND PREVENTION

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Dr ing O T Blindheim

Abstract
In 'hard rock' tunnelling on the Norwegian mainland, the geological conditions are often favourable. However, in most tunnels, there is a potential for geological hazards to develop into accidents, or health risks, if they are not recognised during planning and construction, and if appropriate preparations are not made. This applies to risk of flooding, collapse in unconsolidated zones, rocks stress problems, poor confinement, crushed or blocky rock masses, and in a few cases, even natural gases.

This paper describes the most common features that one has to be prepared for, and how the situation can be dealt with by pre-treatment ahead of the face, and preventive actions at the work face. Problems and practical solutions are discussed. The suitable organisation and the importance of a focused decision process are highlighted.

Unforeseen geological conditions cannot be used as an excuse for lack of safety precautions. If a feature is 'unforeseen', this may apply to the economic conditions of the contract, but the excuse of 'surprises' must not be allowed with respect to safety, neither to planners, owners, contractors, crew nor anybody else involved.

1 ACCIDENTS ARE CAUSED

Geological hazards have their causes in nature, or in the 'geological conditions'. They may appear to have an element of unpredictability. It may be difficult to tell ahead of time if and when a specific geological feature may be hazardous. However, the safety slogan "Accidents do not happen; they are caused" applies to geological hazards as well as to other types of accidents connected to human activity. Accidents may be caused by lack of preparation or caution.

Typical geological features that represent hazards to the safety and health in tunnelling are:
- Water under pressure
- Unconsolidated clayey or sandy zones
- Rock stress, high, low
- Crushed or blocky rock mass
- Gas

Whether such potential hazards are allowed to develop into accidents depends not only on the severity of the conditions, but to a large extent on our actions. Such 'organisational' causes may be:
- Lack of clear allocation of responsibility
- Lack of relevant experience
- Insufficient preparation, equipment, procedures
- Lack of or wrong decisions

The consequences of accidents may be:
- Loss of life
- Damage to health
- Damage to property, in or outside the tunnel
- Damage to the external environment
- Delays, cost overruns, even loss of the tunnel

This paper focuses on the first two aspects.

2 THE TUNNEL FACE

The geological hazards are 'looming' ahead of the tunnel work face, become exposed at the face, but may also cause accidents further out in the tunnel. It is however useful to look first on the situation at the work face, where many tasks are performed and different interests are present:
- 'Actors and roles':
  - Work crew, shift bosses, foremen, supervisors, tunnel management
    - Subcontractors for special activities (e.g. muck transport, spraying of concrete)
    - Owner's representatives, quality and quantity surveyors, geological engineers, specialist advisers
- Information and evaluations:
  - Observations from probe drilling, geological mapping
  - Varied experience, differing viewpoints, interpretations and evaluations
- Economic interests:
  - Work crew bonus system
  - Contractor's profit
  - Owner's costs

Some factors may apparently contradict safety, not at least the time factor, i.e. the ever present pressure for production. During the hydropower boom in the 1960's to 1980's, there were examples where safety was compromised for production and profit, not at least by the tunnelling crews themselves. Such attitudes have been replaced by the realisation that safe tunnelling is also cost efficient [1].

The slogan "Lack of accidents does not prove presence of safety" applies well to the situation at a tunnel work face. Since the conditions vary continuously as tunnelling progresses, one can never let the guard down. Due to the complexity of factors at the work face, one may coin another slogan: "At the tunnel face incidents may easily become accidents".

As in many other situations, safety at the tunnel face can only be achieved by:
- Determined management
- Conscious attitudes
- Prepared procedures
- Quality in execution
- Thorough follow-up

Although sometimes less obvious, this applies to the health aspects as well.

3 CAUSES, EFFECTS AND PREVENTION

Norway is basically a ‘hard rock’ province. This is frequently associated with favourable tunnelling conditions, which may dominate in some tunnels. It does not mean that adverse conditions are not met; geological hazards are indeed present in most tunnels, but the warning signals may be few or not so obvious.

Table 1 gives an overview of the main geological hazards, their effects or potential consequences and preventive actions.

This simplified overview focuses on the situation at the tunnel face and the practical measures that can be taken there. It cannot be emphasised enough that probe drilling ahead of the face is a crucial element in risk prevention or reduction for most of the hazards.

The table is directed mainly to drill and blast (D&B) tunnelling, but applies in principle also to tunnel boring (TBM). Some features may be easier to handle by D&B due to the better access to the face, and the flexibility to change between techniques. One could expect that TBM tunnelling, involving a more ’factory-like’ production, could lean itself to a different learning curve allowing for better safety. There are however no figures available from Norwegian tunnelling to support this. It is known from questionnaires to the TBM operators that they fear health risks connected to vibration, noise and dust more than the risks of acute accidents. See also paper no. 2 in this publication

Table 1 Overview of main geological hazards with potential for accidents (swelling material may be involved in 2nd, 4th, an 5th column).

Hazard	Water under pressure	Un-consolidated zones	High rock stresses	Poor con-finement	Crushed or blocky rock mass	Gas, methane
Effects or potential consequences	• Flooding • Cave-in • Dangerous drill rod changing	• Immediate cave-in • Cannot be controlled at face	• Rock spalling or bursting • Slab or block falls	• Block falls	• Block falls • Cave-in	• Explosion • Delay of work activities
Warning signals	• Water in probe or blast holes • Inflow through joints in the face • Karstic features	• Water, mud, sand in probe or blast holes	• Drilling problems in stress release cracks • Noises; crackling ‘shots’ • Visible deform-ations • ***May be lacking!***	• Drilling problems in open joints • ***May be lacking!***	• Drilling problems in crushed rock • Drizzling continues with time • ***May be lacking*** in blocky rock	• Bubbles in seepage water • Rotten smell of associated gas
Preventive actions	• Probe drill to localise potential inflow • Pre-grouting and/or drainage • Do not blast until treatment is done	• As for ‘Water under pressure’ • Ground freezing ahead of face	• Scaling, bolting, sprayed concrete • Drill stress release holes	• Pre-bolting ‘spiling’ • Scaling, bolting, sprayed concrete ribs	• For intact contour: sprayed concrete and bolting • For lost contour, water present: cast-in-place concrete lining	• Probe drill • Increased ventilation for dilution and circulation • Measurements and monitoring

4 EXPERIENCES

4.1 Water under pressure

Flooding due to large water inflows in open joints or karst has occurred in several Norwegian tunnels, in particular in declining access tunnels for hydropower plants. These incidents happened before it became more common to apply probe drilling ahead of the face, and caused significant delays [2].

The working conditions during large water inflows may become very unpleasant, less safe and unhealthy, especially due to cold water. However, this author is not aware of any accidents with loss of life in these situations. This applies also to the more than 500 lake taps ('underwater tunnel piercing') performed below sometimes high water pressure, and to the application of this technique for piercing for landfall of subsea pipelines. In all these cases, extensive site investigations and probe drilling are performed as preventive measures.

The combined hazards of water and stability problems are addressed in the following.

4.2 Unconsolidated zones

Zones of unconsolidated material, often standing under water pressure, represents some of the most difficult and potentially dangerous ground conditions which are met in hard rock tunnelling. Most frequent are narrow zones or permeable 'chimneys' along faults, which may be more or less filled with clay or other loose materials. These may cause immediate collapse at the tunnel face if exposed before treatment, or delayed problems in work areas further out in the tunnel where the workers assume that they are safe.

One example is an accident in a road tunnel a few years ago. A water-bearing crushed zone had been supported by sprayed concrete at the face, but collapsed after the face had progressed further, apparently after the water pressure had built up over time against the rock support without giving any clear warning signs. The collapse hit a concrete transmixer that was waiting in the tunnel to deliver concrete for rock support and killed the driver.

The prevention of such accidents depends on the more systematic use of pre-treatment by pre-grouting to consolidate the loose material if possible, combined with drainage holes and heavy pre-bolting. It is also justified to take a close look at whether sprayed concrete lining is sufficient in such cases.

Other spectacular examples of unconsolidated zones have been found in subsea road tunnels. This includes the Bjorøy tunnel, where an exceptional and unexpected zone of 4m width of completely loose sand was encountered. The zone was tunnelled through after heavy consolidation grouting [3]. Recently, the Oslofjord tunnel met a fault zone that had been eroded to unexpected depth and filled in with loose glacial deposits under 120m water pressure. This zone had to be frozen over 30m length to become passable [4]. In both cases, no incidents occurred at the face, as the poor ground was detected at a safe distance ahead of the face by systematic percussive probe drilling. Had such zones been exposed at the face by a blasting round, the tunnels would have been catastrophically flooded, and would perhaps not have been recoverable.

4.3 High rock stress

High rock stresses do not only occur under high cover as high tangential stresses occur also close to valley-sides, or even at low cover depending on the tectonic conditions. Especially in the mountainous fjord landscape of western and northern Norway, such conditions are common. The stress release may cause spalling or rock burst (violent crushing) of the rock. This results in dangerous work conditions; manual scaling may become impossible to perform safely. The sequencing of the rock support becomes important; under very intense spalling, it may be necessary to apply sprayed concrete after mechanical scaling, before rock bolting.

A recent example is the 24.5km long Lærdal road tunnel, with rock cover up to 1450m. On some sections very intense rock spalling occurred. Several smaller accidents and one permanent injury occurred, necessitating a very cautious approach and heavy rock support with fibre-reinforced sprayed concrete and end-anchored rock bolts [5]. On the worst sections, rock flakes could be thrown up to 20m from the face, and spalling could occur from the face during charging of explosives. Under such conditions, the face was supported with rock bolts and sprayed concrete.

The more intense spalling and rock bursts may be accompanied by crackling or gun-shot sounds, providing a dramatic effect and sometimes acting as warning signals. However, moderately high rock stresses may also be very dangerous, as there could be a lack of the warning signals that may follow the high rock stresses. Fatal accidents have occurred in circumstances where rock stress problems are not intense, providing a false feeling of safety. The effect could also be delayed; in the less brittle rocks the deformations may go on for a long time (weeks, months) and could cause potentially dangerous situations further out in the tunnel.

The Lærdal tunnel also offered another example of the influence of high stresses, in the form of squeezing in a fault zone [6]. A major fault zone was met at more than 1000m rock cover. It contained crushed rock and swelling clay, but no water, and was driven through with heavy rock support in the form of rock bolting and sprayed concrete. No fall-out occurred during blasting. After driving 20m through the zone, during an attempt to free a stuck drill rod, a fall-out of 10m^3 occurred and tore the mid boom off the drilling jumbo. This was followed by two more fall-outs of the same size. During application of sprayed concrete to the unstable area, 100m^3 came down and hit the far end of the manipulator arm. Further instability was indicated by sounds and dust coming out of cracks in the sprayed concrete. The potentially unstable area was evacuated and the cave-in filled up with concrete. A stepwise process of applying rock support allowing for deformations was started. In connection with the present paper, it is the immediate situation that is of most interest. The presence of the softer crushed and swelling material was detected during drilling. However, as the immediate stand-up time was sufficient (presumably because of lack of natural water), tunnelling progressed. In retrospect, one can see that the warning signals were there and should have triggered the use of heavy pre-bolting, which was later applied in the remaining part of the fault zone.

4.4 Poor confinement

At the opposite end of the scale, low rock stresses or lack of confinement may cause block falls without any warning whatsoever. This is why it is not possible to rely only on deformation measurements for decisions regarding rock support in blocky ground. A fatal block fall may occur without any warning in the form of measurable deformations. Experienced personnel must make the observations about the conditions at the face, with respect to joint orientations, smoothness, clay coating, moisture etc.

Situations with poor confinement could occur in almost any tunnel; close to portal areas or adjacent to fault zones. It can be more widespread in certain areas, for example in large 'blocks' of rock mass between fault zones releasing the stresses. One example is a coarse grained often partly weathered granite in the Oslo graben (the Drammen granite), which frequently has a loose blocky appearance between released sub-horizontal benches and sub-vertical clay-filled joints or clay gouges, providing no or little interlocking effects. In this situation it is critically necessary <u>not</u> to rely on deformation measurements before deciding on rock support. Pattern bolting with normal length rock bolts may not be effective, as the fall-outs may be very deep. Systematic pre-bolting ('spiling'), combined with rock bands and radial bolts, becomes necessary to avoid large and dangerous block-falls.

4.5 Crushed or blocky rock mass

Collapses or larger cave-ins have occurred on a number of occasions in modern Norwegian tunnelling.

One dramatic example of a collapse without influence of water occurred in tunnel on the Sira Kvina hydropower project. When a Pre-Cambrian intensely crushed diabase dyke under 300m rock cover was exposed over only 1m^2 in the face, it collapsed and filled a certain length of the tunnel with debris. Fortunately, no harm to the crew occurred. The zone was extremely dry. Water had to be injected during freezing of the same zone in the by-pass tunnel

Other, less dramatic, but more frequent examples are small fall-out of crushed or blocky rock from the face itself, or from the crown and walls close to the face, before proper rock support has been installed. Especially in large cross sections these fall-outs can be dangerous. Earlier it was not uncommon to blame such incidents on human error by the face crew for not showing sufficient caution. Today, this attitude is not acceptable; the safety systems shall not allow chances to be taken at the work face. This attitude can be achieved by motivation, proper training and follow-up.

4.6 Gas

Of the hazards mentioned in Table 1, explosive gas is the least frequent one in tunnelling on the Norwegian mainland; methane gas has only occurred in very few cases [7]. One case involved occurrence of methane at the face of an Alimak driven shaft; no explosion occurred and the crew evacuated. In a TBM tunnel, a small explosion occurred at the face without any damage or injury. In both cases, the source rock was likely black schist layers in formations otherwise dominated by phyllites and mica-schist.

Because of the infrequent occurrence in Norwegian tunnelling, there is a possibility that lack of preparedness may increase the connected risks unnecessary. It is therefore important at the planning stage to consider the possibility of occurrence, so that measurements can be applied before exposure. In contrast, the handling of methane in the coal mines on the Spitsbergen island group north of the Norwegian mainland is a necessary routine.

5 OTHER ASPECTS

5.1 Combined effects

Combination of hazards, especially if unforeseen, may easily increase the risk significantly. For example, if gas is occurring unexpectedly and extra ventilation time is needed, this may be detrimental to the stability of zones with low stand-up-time, thus the combined effect may become critical.

Trivial factors, not normally connected to hazards, may contribute significantly to increase the risks, especially if they are delaying preventive actions, e.g. rock support in zones with low stand-up-time. This may include breakdown of equipment when no spare parts are available etc.

5.2 Delayed effects

One also has to remember that the hazards may be 'looming' further out in the tunnel, not only at the face. As mentioned, slow rock stress redistribution may cause large rock slabs to loosen and fall, if the problem has been underestimated or not recognised. This has unfortunately been the cause of several fatal accidents over the years. This threat to work safety has recently been reduced by the more consistent use of and complete coverage by rock bolting and fibre-reinforced sprayed concrete in situations where long-term stress relief may take place.

A delayed effect may also apply to gas, which could seep in over longer sections of the tunnel, not always noticeable visually or by smell. Again, the low probability of hitting gas in some rock formations may represent a hazard in itself, if checking is not performed 'to be on the safe side'.

5.3 Pre-treatment

As discussed, the decisions whether to implement pre-treatment ahead of the tunnel face, is crucial for the work safety and for the success of the project. This includes pre-grouting and/or drainage or pre-bolting ('spiling') depending on the situation. The equipment and procedures for these needs are now available on any Norwegian tunnel face, by practise or contractual regulation.

5.4 Movable formwork for 'face plugging'

An example of preparations is the contractual requirement for all subsea road tunnels to prepare a movable formwork, with the possibility to close and plug the face with concrete. Such formwork shall be mobilised ready for use before the tunnel face is driven out under the sea. This has become a standard contingency since the support of a face collapse had to be improvised in the first subsea road tunnel at Vardø. In the Ellingsøy subsea road tunnel on the Ålesund project, such a formwork proved useful to stabilise a cave-in caused by the lack of pre-bolting in a major fault zone. The zone caved upwards at a rate of 1 metre/hour, but stopped - leaving 2/3 of the rock cover intact. [8].

5.5 Ground freezing

Ground freezing is normally not mobilised ahead of tunnelling. In the recent case of the Frøya subsea tunnel however, due to the foreseen possibility of extremely poor ground conditions in fault zones, the option to perform ground freezing was included and priced in the tender documents [9]. Preparations were made to reduce mobilisation time for the freezing equipment.

6 HEALTH EFFECTS

While it is necessary to focus on the hazards connected to adverse conditions and the potential for dramatic accidents at the tunnel face, the potential health effects due to geological conditions must not be forgotten.

6.1 Quartzitic dust

The hazard of dust from quartzitic rocks has been understood for a long time; it still poses significant challenges with respect to prevention, which mostly must take place by minimising the spreading of respirable dust (e.g. by watering the blast pile before and during loading) and sufficient ventilation. On TBMs, dust suppression during boring, suction ventilation from the cutterhead and dust filtration is now standard equipment. It is important to keep the equipment and work space clean by frequent washing to avoid spreading of settled dust after it dries out [11, 12].

6.2 Other gases

Gases other than methane may present health risks. This applies to:

- Hydrogen sulphide (H_2S), which has no colour and is poisonous. It smells like rotten eggs, but this warning signal fades with exposure time.
- Radon, or rather the 'radon daughters', which are heavy respirable particles that can settle in the lungs and may cause cancer from alpha radiation.

Hydrogen sulphide is not uncommon in limestone formations. Radon is relatively common in granitic rock, but occurs also in other rock types, e.g. in alun schist in the Oslo graben. Radon is also found in syenites, pegmatites, fault zones etc. The radon exposure in Norwegian tunnels and mines has been reduced to about 1/3 of the average level in 1972, primarily due to a general increase in ventilation [7].

Good ventilation is the obvious preventive measure for these gases. For radon it helps to reduce the degree of rock crushing (if possible). Depending on the expected exposure, it may be necessary to apply personal dosimeters to monitor the exposure. In some cases it may be necessary to limit the exposure by limitations to the work time underground.

7 SEISMIC AND LANDSLIDE RISKS

Hazards connected to earthquakes are normally not counted as being part of the risk during tunnelling, although they may get attention as a risk for the operation phase of a tunnel.

The probability of accidents due to earthquake during construction of a tunnel is naturally reduced due to the limited construction time. Modern ductile rock support measures, like rock bolts and fibre reinforced sprayed concrete, provide excellent protection against earthquake damage in the form of block falls. One must however remember that the more common earthquake damage to tunnels is landslides at the portal areas. This means that sufficient temporary protection around and above the portal areas should be in place before tunnelling starts. In a country with repeated freezing/thawing and heavy rain, such potential stability problems around the portal must anyway be dealt with.

Celebrating breakthrough. VERPEN, one of the tunnels in the OSLOFJORD PROJECT.

8 GENERAL PREVENTION

8.1 Skilled tunnelers, co-operation and flexible techniques

The prevention starts at the planning stage, by performing relevant and thorough site investigations. These are not discussed further here, but it is emphasised that irrespective of the amount of site investigations, one must always maintain the respect for the potential variations of nature. Too often has the confidence in the interpretations of the investigations been too high, by all parties involved, and unexpected conditions or 'surprises' occur. In connection with safety, this is not acceptable; one has to be prepared.

Norwegian drill and blast (D&B) tunnelling is traditionally performed with:

- Multi-skilled face crews, organised in autonomous work-teams lead by experienced shift bosses.
- A high degree of co-operation between the contractor and the owner. Normally the primary rock support is designed to become part of the permanent support. Decisions for adaptation of permanent rock support are taken round by round at the tunnels face.
- High capacity modern equipment, flexible procedures for efficient changing between various techniques for pre-treatment of the ground and rock support at the face.
- Extensive use of probe drilling is normal, which is now increasingly supplemented by 'measurement while drilling'.

These characteristics allows for cost-efficient tunnelling, which has been highlighted in numerous papers in this series of publications as well as other fora, e.g. technical conferences about rock support [10]. The applied techniques provide safe tunnelling if they are utilised in the right manner. With a skilled workforce, adherence to practical and thorough procedures, close follow-up and timely decisions, the basis for achieving safety is laid.

The frame of this paper does not allow a detailed discussion about all aspects of the available techniques, which includes:

- Reduced blasting rounds
- Excavation of part cross sections (pilots)
- Mechanised scaling, sprayed concrete (including reinforced ribs), bolting
- Mobile concrete formwork with face closure possibilities

In relation to the focus on the activities at the tunnel face, it is emphasised that one has to:

- Choose the suitable stabilisation measure
- Dimension robustly
- Include stabilisation in the work cycle
- Not delay the stabilisation: keep rock support up to the progressing face
- Watch out for 'warning signals', to be conveyed to everybody involved

For example, it may be crucial not to postpone pre-treatment ahead of face or stabilisation at the face until after a weekend brake. This necessitates proper procedures, positive attitudes and suitable payment systems.

One has to take into consideration the different focus of attention. For example: the face crew is naturally concerned about face and roof stability, but may pay less attention to the detailed stability of the walls, unless the procedure calls for permanent rock support (including the walls) to be performed at the face. Other workers further out in the tunnel may be less observant of the varying conditions and less familiar with rock works than the face crew. Their tasks may be close by the walls, which may expose them to block falls from the walls. Such risks can easily be minimised by adherence to proper procedures.

8.2 Decisions are crucial

The decision process is crucial. This includes:

- Responsibility and authority must be allocated and understood.

- Delegation of tasks has to follow clear criteria, e.g. under which conditions excavation may proceed or shall be stopped.
- The need and procedures for 'feed-back' of observations must be clarified.
- A delayed decision may aggravate problems.
- Criteria for mobilisation of contingency or emergency measures must be clear.

Preparation is mandatory for contingency measures. This applies to:
- Mobile formwork
- Extra water pumps
- Spare supplies of rock support measures, grout material etc.

While contingency measures and procedures must be in place, the focus of the effort has to be on the prevention. This applies to the necessary pre-treatment and checking whether it is sufficient before the next blasting round is taken. This necessitates skilled contractors and crew, and experienced geological engineering follow-up.

Although the contractor to a large extent will have the executive responsibility for safety, it does not, according to Norwegian laws, relieve the owner of his overall responsibility for safety. This requires active participation on his part, not only in the form of receiving and reviewing the contractor's reports.

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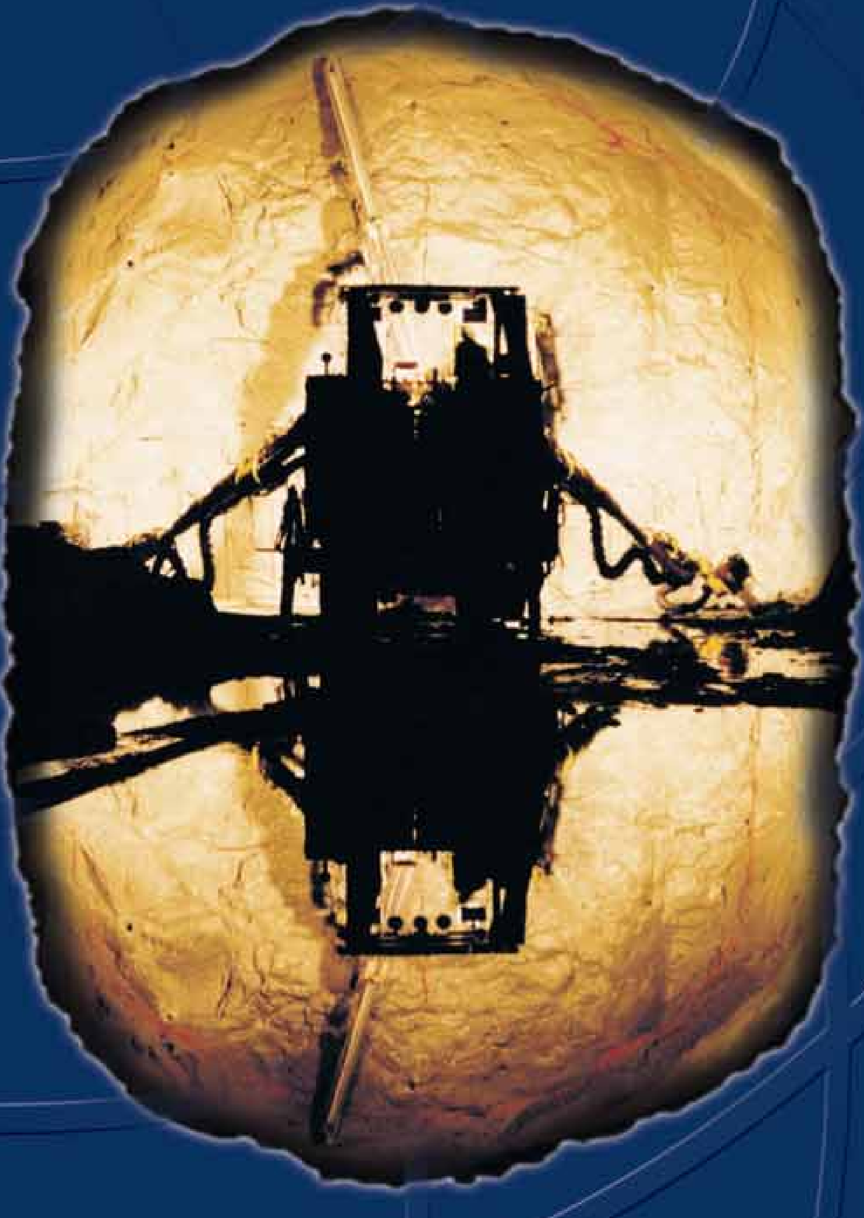
UNDERGROUND CONSTRUCTION TECHNOLOGY



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5 HEALTH AND SAFETY SYSTEMS

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1 INTRODUCTION

It is less expensive to spend time and other resources to prevent accidents, loss of lives, health injuries or material damage than to cover loss in the aftermath of accidents. Preventive actions is the basic approach in safety philosophy and should be the guiding principle in underground excavation. A good saying goes "If you think Health & Safety work is too costly, try an accident!"

Through active H & S efforts several tunnelling contractors have experienced increased productivity and economical benefits. That is a bonus, priority number one must always be to avoid accidents, save health, lives and material goods.

Industrial enterprises and authorities which more or less continuously retain contractors to execute projects have an independent responsibility to secure that project implementation meets laws, regulations, standards with emphasis on safety, health and environmental issues. Common practise is to submit requirements as to qualification of personnel, quality control and assurance plans as part of the tendering documents. This approach is vital for the overall progress of complex projects, also of importance for reputation and public support.

Some of these clients will examine the proposed H&S plans, the relevant resources and previous achievements as closely as they will examine the technical solutions and the price setting.

The suggestions and thinking as found below reflects observations and experience from safety management during the last two decades

2 LEGISLATION AND THE CONSEQUENCES

Before 1977 the construction industry in Norway had some 40 fatal accidents per year, some of these within tunnelling.

The Working Environment Act put into force 1977, regulates the responsibility of the employer towards employees and society. Safety, health and environmental aspects were put into focus and practical results could be recorded. During the period from 1988 till 1995 fatal accidents were reduced to 10 per year. During the 1990s several new regulations under above mentioned act were introduced.

Enhanced emphasis and awareness have further decreased the number of fatal accidents in the building and construction industry, e.g. down to 4 in 2001.

It seems obvious that the positive development is caused by an overall changed attitude to safety, health and environmental matters, in first hand through active work within the industry: thorough planning, tidy worksites, improved safety procedures, strict conduct of quality requirements and keen interest from company top executives. In the period of the last 20 years the Accident Rate (H) in one of the largest construction companies decreased from H = 35 to H = 8. Several large construction projects reached the zero vision of H = 0. During the year 2002 the construction division of mentioned company recorded H = 2.5
(H = number of accidents causing absence from work per one million working hours).

Important regulations under the Working Environment Act regarding concerning rock blasting and tunnelling sites are referred to before, we repeat:

- Regulation of Health and Safety in Connection with Rock Work (1997)

- Safety, Health and Working Environment on Building- and Construction Sites (1995).

The latter requires the Owner (Client) to prepare Health and Safety Plans for his projects based on Risk Analyses. These plans shall be included as cost items in the tender documents submitted to the contractors.

In June 2002 the new 'Act relating to fire and explosion hazard and fire prevention' and the new 'Regulation on Handling of Explosives' came into force. The new regulations require a 'Rock blasting plan'. Input to such plans are i.a. risk analyses.

Previously the shotfirer carried the responsibility for blasting operations, a situation long overdue. Today all parties are responsible. The Owner, if not himself competent, is responsible for retaining qualified contractors with skilled personnel. The contractor as legal entity, its top management, the project administration and the shotfirer are all exposed to responsibility. Hence, owners and contractors which do not employ rock blasting specialists have to hire competent personnel.

The Owner`s plans, defining the responsibilities and requirements to plans, reports and execution shall be part of the tender papers, thus demanding price setting for the different safety precautions. That shall secure that relevant contracts allow costs for processes and procedures required by laws and regulations.

3 GENERAL HEALTH AND SAFETY PLAN FOR TUNNEL PROJECTS

As an introduction to the required health and safety efforts, one will below find the typical content of an overall H&S plan. The plan outlined below complies with the already mentioned 'Regulation of Internal Control', 'Regulation of Handling of Explosives' and 'Regulation of Health and Safety in Connection with Rock Work'. It should once more be underlined that governmental agencies and major private sector companies within general infrastructure and oil development put emphasis on the Health and Safety plans submitted by potential contractors as integral part of the tender. General reputation and achieved results concerning health, safety and environmental issues are other important aspects when selecting the successful tenderer. The low bidder is not always winner of the contract..

3.1 Table of contents - Distribution list (plans, reports etc.) - General information

- Contractor’s own expectations:
  - To execute the project within the framework of the contract in terms of economy, progress, quality and safety.
  - To execute the project without personal injuries or harm to the external environment.
  - To maintain the site and rig area tidy and orderly at all times.
  - To maintain good co-operation with the client, other contract parties, third parties like neighbours, landowners
- List of addresses and phone numbers.

3.2 H&S Plan

The project H&S plan is based on the contractors Quality and Internal Control System and is adapted to the project in compliance with laws and regulations, standards and the Owner`s requirements. (The Owner is responsible for Risk Analysis and his Rock Blasting Plan as part of his H&S Plan for the project tender).

- Documents.
  - List of applicable laws and regulations.
  - List applicable Norwegian Standards NS.

3.3 Organization. Responsibility.

The full responsibility for H&S work lies with the line management.The H&S personnel are managing their tasks on the project on behalf of the site manager and his superiors.

- Employer responsibility.
  - The board and the managing director of the company have full responsibility on behalf of the company owners.
  - The responsibility is delegated to the site manager level (Working Environment Act §§ 4 and 14).
  - Risk Analysis and the drawing up of the Rock Blasting plan is the full responsibility of the employer as part of the H&S plan. (Regulation of Handling of Explosives § 10 – 9 and Regulation of Health and Safety in Connection with Rock Work § 5).
- Work Supervisor responsibility.
  - Hands-on managers assigned responsibility by the site manager may be classified work supervisors / foremen / gang leaders / operators etc. It is their responsibility to ensure that the work they are in charge of is planned as required and executed in agreement with the plans, i.e. in a safe and responsible manner (Working Environ-ment Act § 16.2).
- Employee responsibility.
  - The employees` responsibility is to assist in the implementation of the actual plans and to safeguard that all precautions introduced to create a healthy and safe working environment are utilised and also to participate in the employer's health and safety work (Working Environment Act § 16.1).
  - The Shotfirer is especially responsible for the technical execution of the blasting according to the blasting plan. He shall also be a member of the planning team. He shall check that all safety precautions are according to plan, he is also responsible for the correct drilling of holes. He shall inspect the holes and check the report from drilling before charging. After the round is blasted, he shall prepare the Blasting Round Report (Regulation of Handling of Explosives § 10 – 8).
- Organisation Chart.
  - Organisation charts shall be available showing responsible management and H & S personnel and names. This is an important part of the documentation necessary in case of accidents and subsequent investigation of the incident.

- Job descriptions with respect to H&S work on site.
  - Everybody at the site, managers on all levels and operators, H&S personnel, the Safety officers and Safety delegate have their personal job description in respect of responsibilities in the H&S field.
- Coordination of H&S work on site with more than one employer.
  - Organization and tasks for the main contractor (coordinator) and his subcontractors or others with contract with the client. The objective is to ensure that all H&S measures are taken care of by all parties on site (Working Environment Act § 15 and Internal Control Regulation § 6). This is very important when a contractor uses a subcontractor on the blasting part of the contract. The drawing up of blasting plan shall be done in cooperation.

3.4 General H&S Routines and Procedures on the project.

- H&S activity plan.
- Action plan. Showing every person`s responsibilities.
- Evaluation of tasks.
- Job Safety Analysis.
- Reporting of near misses, dangerous actions and conditions.
- Reporting of accidents and injuries.
- Safety inspections with reports.
- Daily Safety Planning at team level.
- Handling of H&S issues.
- Health and environmentally hazardous substances.
- Mechanical equipment.
- Chain lifting tackle
- Certificates of personnel and mechanical equipment.
- Operating permits, for example Hot Work Permit.
- External environment.

3.5 Special Additional H&S Routines and Procedures of Handling of Explosives and Blasting Operations

- Drilling. To check correct drilling versus plans. This is extremely important for drilling on high benches and long rounds in tunnelling. Blasting Round Plan.
- Charging of blast holes in accordance with Blasting Round Plan showing types and quantity of explosives, ignition system and stemming.
- Protection to prevent fly rock (where applicable).
- Warning procedures, postings.
- Immediate action subsequent to firing: Check if successful shot, if successful release area, adequate signal, continue work
- In case of misfire, activate relevant procedure.

Normal shot:

- Scaling by hand ore by machine.
- Finish and submit Blasting Round Report

Other activities:

- Surplus explosives, detonators etc have been brought to intermediate store and locked up. Return to producer or other store as the case may be. Transportation of explosives and detonators to take place in agreement with the ADR. specifications. Internal transport and stationing (placing) of explosives and detonators. Special machines and equipment related to explosives and blasting to conform to EU-regulation, CE marking.

3.6 General Emergency Preparedness Plan. Contingency Plan.

- Introduction. Risk analyses.
- Emergency preparedness areas.
- Emergency preparedness organization. Responsibilities.
- Emergency preparedness equipment.
- Heliport. Map references.
- External resources. Ambulance. Fire brigade. Police.
- Notification procedures.
- Training of own personnel together with external resources.
- Action Plans. Team training, how to proceed effectively.
- Information procedures internal and to media.
- Telephone lists always available.

3.7 Special Addition to Emergency Plan for tunnels and caverns.

Underground fire fighting and rescue procedures.

- Organization chart. Responsibilities.
- Escape routes if any, including shafts and tunnels.
- Personnel access control system, in operation at all times.
- Fire extinguishers on all machines and trucks.
- Self Savers (light active coal filter masks) for every person underground and on the different machines.
- Safety (rescue) container.
- Communication system to the surface
- Drawings of the whole underground system with marking of niches, safety containers, escape routes, electrical installations etc. for the use of the management and external resources (smoke divers) etc.
- Emergency plans for ventilation. Usually one should not stop the ventilation if personnel is trapped.

3.8 H&S Instructions and Procedures.

- Breach of safety regulations must lead to disciplinary actions.
- The use of personal protective equipment supplied by the employer shall be used. (Hard hats, protective eyeglasses, ear-protection, booths, special cloths)
- Drugs, licquer etc banned from site
- Personal tidiness

4 GENERAL COMMENTS

The Safety Plan as outlined in key words is of general nature. A full plan with details is beyond the scope of the paper. It should be read as guidelines and help in the preparation of a rather complex programme where local conditions, scope of work, available machinery, equipment and technology must be considered.

Table 1 indicates the large variety of potential hazards that present dangers of personal injuries in tunnels, based on risk analyses made by domestic contractors. It is of importance that personnel working underground recognise the special risk factors, that everybody depends on the behaviour of their colleagues, that the managers care for the work force, that top priority is given to health and safety aspects.

Table 1: Risk factors concerning personal injuries in tunneling (The Shotfirer's Manual, Norwegian Tunnelling Society, NFF 2003)

Item	Block fall	Explo-sion	Fire	Rock burst or fly rock	Objects into eye	Gas, Dust	Injury due to elec-tricity	Topp-ling, fall injuries	Traffic	Pinch injury
Drilling	X	X	X	X	X		X			X
Charging holes	X	X			X			X		
Blasting	X	X		X		X				
Loading	X		X	X		X	X		X	X
Scaling from pile	X				X	X		X		
Machine scaling	X	X			X					X
Watering pile	X						X		X	X
Transportation	X		X	X		X			X	X
Scaling from basket	X					X		X		X
Storing of explosives		X	X							
Placement on site of explo-sives		X	X							
Internal transport of explosives		X	X							
Storing of fuel and oil		X	X							
Storing of gas		X	X			X				
Ventilation work					X			X		X
Grouting of bolts *)	X				X	X		X		X
Electrical work	X		X		X		X			
Hot work		X	X		X					

**) Some chemical additives for grouting may cause skin injuries*

6 BUILDING A HSE SYSTEM STEP BY STEP

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Abstract
There is a potential for improvement of the HSE situation in Norwegian tunnelling and other underground work. The Safety Element Method (SEM) is a tool for such improvements, developed for avoidance of accidents and loss. SEM presents an improvement process as a 'stairway' with five steps, where each next step represents a higher level of performance. The members of an organisation co-operate to determine which level they are on today, and which level they would be best served to reach. Based on these results, measurements and plans of action will be worked out and implemented in the organisation.

1 INTRODUCTION

Although matters have improved the last few years, occupational accidents are a persistent problem of Norwegian tunnelling and construction work. Having to work within a potentially hazardous environment, the industry has previously had high accident rates combined with high severity of the accidents, compared to other industries.

This fact has emphasised the need for a structured and adapted tool for internal HSE development and improvements. The application of a formal tool makes the HSE work more systematic and effective, and insures that important factors are addressed.

The Safety Element Method (SEM) has been developed to motivate for internal HSE improvements and for development and implementation of positive HSE measures and activities in the organisation. Briefly summarised, the method helps to find out where the organisation is today, where it should go, and how to get there.

2 THE SAFETY ELEMENT METHOD

Tables, or matrices, constitute the SEM. Elements essential for safety performance are listed in the columns of the matrix, see Figure 1. Five stages of performance within these elements are defined in the rows. The general model in Figure 1 shows the framework of the main matrix, which gives the six key safety elements. Details within the elements are considered in sub-matrices, one for each of the main safety elements. The content of the main matrix is shown in Table 1. The sub-matrices are not presented in this article.

The main issue of the stages is to visualise improvement potentials to guide enterprises towards organisational development. The method is founded on the principle of consensus. An internal group in the enterprise shall assess their own organisation based on the matrices, to decide which stage they are on, and which stage they would be best served to reach (profile A and B in Figure 1, see also Table 1).

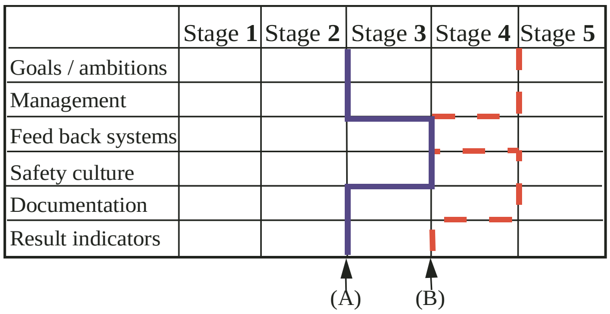

Figure 1 The general model of the Safety Element Method. Presentation of current state of organisation (profile A) and the desired future state (profile B).
Provided the group members have defined an improvement potential, i.e. there is a difference between the current state and the desired future state, they shall work out strategic plans and measures suited to attain their goals.

Table 1 Internal analysis by the Safety Element Method, main matrix. Current status *should be marked by ✘ and the desired situation by ✔ in the windows (☐). For every stage, fulfilment of the previous stages is presumed. Sub-matrices are connected to each element. (Sub-matrices are however not presented here.)*

	STAGE 1	STAGE 2	STAGE 3	STAGE 4	STAGE 5
1. Goals/ambitions	☐ Goals are missing.	☐ Ambitions are to satisfy regulations.	☐ Goals and ambitions go beyond regulations.	☐ Goals beyond regulations. Company matches the best.	☐ Working to influence and improve regulations.
2. Management	☐ Modest obligations to safety work from management.	☐ Follow-up of accidents. ☐ Weak HSE management gives small consequences for line managers. ☐ Mainly local treatment of risks.	☐ Management actively engaged in safety work. ☐ Breach of HSE instructions brings reactions for everyone. ☐ Systematic safety work. ☐ Focus on technical and human failures.	☐ Safety is equally prioritised and followed-up as production and quality. ☐ Comprehensive views and systematic approaches characterise safety work. ☐ Strong focus on organisational and management factors.	☐ Strong management commitment and obligations to improve safety culture. No self-satisfaction. ☐ Line management is good models.
3. Feedback systems/ learning	☐ Casual transfer of experience.	☐ Simple statistics. ☐ Mainly short term corrective actions.	☐ Thorough statistics. ☐ Deviation control. ☐ Action plans and measures are worked out. ☐ Time schedules are kept.	☐ Proactive seeking for improvement, continuous preventive measures. ☐ Thorough process when working out action plans.	☐ Extensive and systematic exchange of experience with other enterprises.
4. Safety culture	☐ Mastering risky challenges is the ideal.	☐ Little extra done to work safely. It is more essential to finish fast.	☐ Mainly seeking safe behaviour, sometimes chances are taken.	☐ Safe behaviour is a matter of course. ☐ The employees are actively seeking each other's experience.	☐ Always safe working methods, never breach of routines. ☐ All employees work actively to obtain a working environment without losses.
5. Documentation	☐ Small amount of formal routines.	☐ Satisfies minimum requirements.	☐ Comprehensive documentation. ☐ Improvements following revisions.	☐ Plain and practical documentation. ☐ Procedures are accepted, and followed by most employees.	☐ Documentation is well known, always up to date, and followed.
6. Result indicators	☐ No result indicators (except economic ones).	☐ Absenteeism and accident statistics are the only result indicators.	☐ Extensive use of HSE-results as result indicators.	☐ Co-ordinated and integrated goals. Relations between personnel damage and other losses are visualised through result indicators.	☐ Has received international awards for the HSE and quality management.

In managing safety and preventing loss, the problems are not always easy to identify, and certainly, they are not easy to solve. The SEM process is performed in a structured group setting, including workers, managers and staff. The point is that people with different background and experience should have better chances in finding practical solutions.

SEM focuses the importance of improvements during a development process. No enterprises should try to reach the top of the mountain in one day, one month or even a year. The HSE system must be built up through a continuous internal process, step by step.

3 ACCOMPLISHING THE ASSESSMENT

The way of accomplishing the SEM assessment is regarded as an important part of the tool. A basic assumption of SEM is that a common realisation about the situation of today and about future goals is a necessary basis for organisational change. Thus the intention is to make available knowledge and common sense from different organisational levels interact.

The enterprises' internal improvement activity will be carried out in two parts, where the first part is the assessment of the current situation and the desired state (profile A and B in Figure 1), and the second part is the compilation of measures. The tool has been constructed for promoting internal discussions, and both these parts will take place through group processes. The mutual definition of the states A and B ensure that the local experiences of the participants are brought forward. The members of the internal SEM group will have an equal chance to express their views. The group assessments will be introduced by an individual evaluation of the current and desired state of the organisation. The individual judgements, which are applied to reduce the risk of any dominant participants controlling the common assessment, form the basis for the group discussions.

Participators in the assessment should come from different places and levels of the organisation, i.e. line management, employees and the safety supervisor. The recommended size of a working group is five to seven persons, in order to optimise efficiency and creativity. Composition of the group, depending on which part of the company they are going to represent, must be decided beforehand. The group may represent a single department, two (or more) tightly connected departments, or a whole enterprise.

The next step of the internal improvement is to work out the improvement measures that shall be implemented in the company. SEM also contains a check list of safety measures to help during this part, as a supplement to the measures directly introduced through the sub-matrices of SEM.

The SEM assessment and the subsequent development process should be rooted in the Work Environment Committee (WEC) of the enterprise. The WEC must give the framework and define whose responsibility it is to manage the process. The WEC must also evaluate and confirm the results from the internal group.

SEM is made for internal use in enterprises, without the help of experts. However, introduction of the method and start of the work function best with the help of a person who knows the method and its process well.

4 EVALUATION OF SEM

Through the work of a doctoral thesis at the NTNU (the Norwegian University of Science and Technology) SEM was implemented and followed in four enterprises (Alteren, 1999).

There was one overall research question in this evaluation study: "How does the Safety Element Method function in the companies?" This question was divided into three main areas for investigation:

- First of all: Does the method generate any activities and change? The intention of the tool is to generate improvement activities to obtain better safety results. Thus, the tool must be relevant for working out measures. Positive development should also preferably be reported.
- Secondly: How do the participants evaluate the tool, what are their experiences? Do they find the method valuable and trustworthy? The opinion of the users is essential. If the users are not satisfied, the tool will not be used.
- The third area discussed was the validity of the tool. The questions were: Are there correlation between the internal assessments and the safety results of the organisations? Do the internal assessments correspond to an external review? What about internal changes – are they reflected in the assessments?

5 FIRST RESEARCH QUESTION: DEVELOPMENT OF MEASURES

The first research question addressed the generation of activity. By using SEM all the companies prepared well founded action plans, adapted to their own conditions.
All together the companies have worked out 56 measures during the process. These measures were classified to find out how effective they can be expected to be. The results show that most of the measures were classified as preventive measures with expected long term effect.

These measures were compared to measures that were worked out as a result of incident investigations in the same four companies. The results showed that these measures had less long term perspective. Most of these measures were simply correction of deviations.

The analysis suggests that the Safety Element Method has resulted in more effective preventive measures that give more long term solutions to safety problems.

The participants expressed that the measures they had developed aimed at the most important areas for improvement of their own organisation. They also told that these measures would not have been implemented without the help of SEM.

It is emphasised that these measurements did not require any expensive investments. What they however did require was, time and attention paid to the safety area. They also required more effort from management.

6 THE SECOND QUESTION: PARTICIPANTS' EXPERIENCES

The second research question dealt with the experience of the users. All the involved persons were interviewed, in order to investigate their opinion. They meant:

- The method had presented a new arena for constructive dialogue about internal safety practices and common challenges. The method proved to be a contribution to bridge gaps between managers and operators. The SEM process had given better co-operation between management and employees, as well as a more common insight in internal problems and challenges.

- Several of the participants mentioned that SEM had a motivating and useful approach to organisational development. The focus on the present situation and on the desired future state had given them a broader understanding of safety management and organisational development.

Altogether the participants found the work rewarding. They felt that they did something useful for their colleagues and for the whole organisation – i.e. building a better HSE system for the company.

7 THE THIRD QUESTION: VALIDITY OF SEM

The participants meant that the judgement of the current status presented the HSE conditions of the company in a credible way. They were very confident with their own profiles, which they claimed presented their company in a nutshell.

The groups' own judgement actually agreed with an external expert review of the companies.

The lost time injury frequencies of the companies were also studied. In general, the results indicate correlation between the internal subjective assessments and the other data collected.

This suggests that the company groups with the help of SEM made rather realistic assessment of themselves and their own company. Thus the results in general indicate correlation between the internal subjective assessments and the other data collected.

8 CONCLUDING REMARKS

SEM has proven to be a valuable approach in building and improving the HSE system of an enterprise.

It is reminded that there is one factor that has the most vital importance to the results of the HSE efforts, no matter what system the enterprise choose. That is management commitment and management excellence in HSE matters. Without active management involvement, any HSE tool or system will fail.

It feels natural to compare the role of management to the role of parents: you need to invest time and effort, founded on genuine interest, in those you are bringing up (leading).

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7 DEVELOPMENT IN VENTILATION METHODS

Jan Lima, Mesta as
Olav T Blindheim, Dr ing O T Blindheim

Abstract
Good ventilation, a result of a well designed and well established ventilation system, is paramount for a satisfying work environment while excavating underground tunnels and openings. Administrative norms give ceiling values for acceptable concentrations of various substances. This paper covers methods of ventilation and case stories.

1 BACKGROUND

1.1 Health risks

Sufficient ventilation is crucial for the work environment with respect to health. Toxic gases and particulate pollution create health hazards if breathed in too high concentrations for too long time. Ventilation is also important for other factors; e.g. reduced sight due to dust increases safety risks.

1.2 Administrative norms

The so-called 'administrative norms', which represents limits for acceptable concentrations of gas, dust and fumes, are determined by the Directorate of Labour Inspection. The norms are set from medical, technical and economical evaluations. An overview is given in Table 1.

The limits are normally given as the highest acceptable average concentration over an 8 hour work shift. Higher concentrations are allowed as short time peak value (aggregate time with high concentration less than 15 minutes per shift), if compensated by lower concentrations during the rest of the shift. However, for some substances with risk of acute poisoning or irritating effects the maximum concentration ('ceiling value') is given. This applies to NO_2 with limit 2ppm and aldehydes with limit 1ppm.

Basically, there are three ways of satisfying these norms:
- to reduce the pollutants to start with, e.g. by using explosives with less pollutants, watering the blasting round to suppress dust, using cleaner diesel fuels (see paper no. 9 in this publication);
- to reduce the exposure, i.e. ventilating the blasting fumes during meal breaks, using machinery (loaders, trucks) with protected cabins;
- to provide sufficient ventilation to thin out the pollutants to acceptable concentrations.

This paper is concentrating on the latter. However, as a background, the development towards less polluting explosives is commented upon briefly below.

Table 1: Norwegian administrative norms for acceptable concentrations

Substance	ppm	mg/m^3
CO carbon monoxide	25	29
CO_2 carbon dioxide	5000	9000
SO_2 sulphur dioxide	2	5
NO_2 nitrogen dioxide	2	3.6
NO nitrogen oxide	25	30
NH_3 ammonium	25	18
Nitroglycerin	0.03	0.27
Formaldehydes	0.5	0.6
Dust: total dust (all dust < 10μm) respirable dust (75% of all dust < 5μm)		 10 5

1.3 Emulsions and slurries

Slurry explosives have been used for more than 30 year in above-ground mining and quarrying in Norway. It is characterised by high effects, good water resistance and good handling safety. Emulsion explosives underground were first used in 1994 for a test programme in the Masfjord tunnel in Hordaland in western Norway. This continued in the Lærdal tunnel. In 1994-1995, the Public Roads Administration, Dyno Nobel and Department of Construction Engineering at NTNU performed a development project in the Hanekleiv tunnel in Vestfold, where emulsion explosives were used for the first time for regular tunnelling, (Elvøy et al, 1996, see also paper 8 in this publication)

The results from the tests and the production comparisons between emulsion and ANFO show that:

- emulsion and anfo explosives have comparable blasting effects;
- by water inflow, and in down-sloped tunnelling, emulsion explosives are advantageous due to its water resistance;
- emulsion explosives gives a significantly improved work environment, in particular by reduced concentrations of NO_2 and CO_2 and by reduced dust from the blasting round resulting in improved sight;
- emulsion explosives also reduce the outlet of blasting fumes to the external environment, of particular importance for tunnelling in built-up areas.

Since then, emulsion explosives are rapidly taking over the tunnelling market in Norway. The Norwegian Public Roads Administration considers the use of emulsion explosives as preferable in long tunnels and for projects in cities. In the 7.2km Oslofjord subsea road tunnel, completed in 2000, the contract specified the use of emulsion explosives (Øvstedal, 2003).

2 TWO-WAY VENTILATION

2.1 Requirements and principles.

During the 1990s two-way ventilation used to be required by the Ministry of Labour and Government Administration, Department of Working Environment and Safety for tunnels with cross section above 32 m^2 and at the same time being longer than 1km. This requirement was adapted to the use of ANFO. The purpose was to improve the work environment in the tunnel, by evacuating the blasting fumes rapidly by blowing them out through a duct, so that they do not pollute the tunnel air behind the work face. This is especially useful when it takes too long time to wait for the blasting fumes to be blown out all the way along the tunnel drive. Rapid evacuation allows work activities at or behind the face to start with less delay.

Two-way ventilation can be achieved by one or two ducts.

One duct is sufficient for tunnel drives with up to typically 5km to the work face, but has been tried for longer tunnels as well, e.g. for the 11.5km drive from the southern portal of the Lærdal tunnel. This solution utilises a mobile platform with a mounted fan, which is used close to the work face, and blows out the blasting fumes in a short time through the same duct as used for the normal 'blow-in' ventilation. The advantages are fast removal of the blasting fumes, and lower costs than two-duct solutions. A disadvantage is high requirements to the tightness of the duct to avoid pollution of the tunnel air due to leakage. The blow-out air velocity must be high to avoid settlement of dust in the two-way duct, as the dust otherwise could be blown back into the face at a later time.

Two ducts, one for blowing in and one for blowing out, is a suitable solution for long tunnel drives (> 4-5km). The advantages are fast removal of the blasting fumes, continuous supply of fresh air from the surface, and the possibility of turning the air flow in the second ventilation tube to improve conditions both at the face and along the tunnel. Also for this solution, the tightness of the blow-out duct is important. The costs are significantly higher than for one duct solutions, typically 50%. It requires more space, which could be limited by the available cross section.

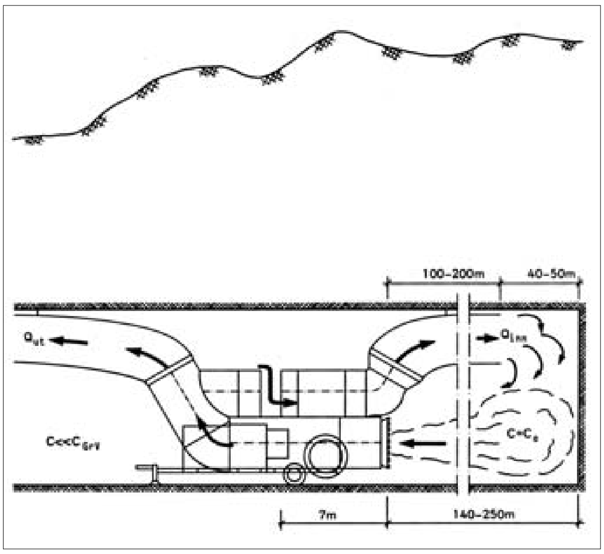

Figure 1: Picture shows a mobile ventilation unit.

2.2 Case story Lærdal tunnel

The 24.5km Lærdal road tunnel was constructed 1995-2000. The contractors were NCC Eeg-Henriksen Anleggs AS from the Lærdal side and the Public Roads Administration, Sogn og Fjordane Construction

Division from the Aurland side. The experience presented here refers to NCC Eeg-Henriksen's lot, which included an access tunnel down to the 1/4 point of the tunnel and two drives of 6 and 7 km respectively.

The explosive used were anfo. The loading machines were Volvo L330 C (60 tons with 6.5m^3 side-tipping shovel); i.e. modern machines emitting less gases in the exhaust than usual for older loaders (Nilsen, 1998). The main drainage ditch was blasted together with the face. Behind the face, permanent drainage, channel for electrical lines, as well as a high voltage line, were installed in parallel with the work at the face; normally at a distance of 600m-800m behind the face. At regular intervals the roadway was laid down, including asphalt (except the top layer). A large part of the permanent technical installations were installed while excavating of the drives took place. This reduced the overall construction time for the long drives, but put extra demands on the ventilation.

The ventilation was indeed a challenge; towards the end of the drives the air needed was approx. 8,000m^3 per minute. For each of the two tunnel drives two ducts of diameter 2.0m supplied air to the face pushed by two fans AL 17 of 230kW through Protan Ventiflex ducts. (with effect steps of 30, 70 and 230kW). One duct was used for blowing towards the face, the other used also for blowing the blasting fumes out by a movable Gal 14, 110kW fan for each face. The operation of the fans and the regulators was controlled by a radio-system, initiated by push-button panels installed at different locations in the tunnel. In this way the tunnel crews could adapt the ventilation to the actual activities; drilling, blowing out the blasting fumes, loading, transport, rock support, installations etc. Through monitors at the site office, management could observe which activity were on.

The ventilation cycles typically ran:
- When the round was blasted, the outer fans were initiated and ran at full blow (step 3) in both ducts for 5 minutes;
- After 5 minutes, the two outer fans were geared down to step 2 and both directed to one duct only. The movable face fan started blowing out through the other duct. This period lasted until the blasting fumes were out;
- The outer fans then took over again, blowing towards the face through both ducts, while loading and transport were took place, or they were geared down while other less demanding activities took place.
- All these functions were remote controlled and could be operated by computers in the site office;
- Several safety functions were built into the system: e.g. prevention of fans blowing towards each other, locking function to use during duct installation and repair, emergency stop function, manual operation etc.

The air quality was measured in 24-hour periods for NO_2 and CO. This took place several times each week at different locations in the drives. Additionally, air pressure and air check for any leakage, to safeguard systematic maintenance and planned ventilation capacity. The results were satisfying with generally good air quality.

During some short periods of 5 to 15 minutes the gas concentration exceeded the administrative norms. This happened during loading only. The large duct diameter saved energy. The access tunnel, however, had to be enlarged from a cross section of 56m^2 to 64m^2 to provide sufficient space for the ducts and the truck transport.

Figure 2: Large fan.

3 INTELLIGENT TUNNEL VENTILATION, ITV

3.1 Development project

The development project "Intelligent Tunnel Ventilation" was based on an agreement of co-operation between (1) The Public Roads Administration's Central Directorate and their Hordaland Construction Division, (2) The ventilation equipment supplier Protan AS and (3) The Norwegian Industrial and Regional Development Fund (SND). Other companies involved were Telenor (telecommunication) that supplied the control system and Argo/Sichon and BBU (tunnel technology). The project target was to develop a total concept that would contribute to cost effective ventilation, to improvement of the work environment and finally to establish documentation of the achieved results (Lima et al. 1999).

The project included development of new duct materials, new duct jointing and new hook-up systems, as well as recording of air quality and automatic control of the ventilation fans. Emphasis was put on increased flexibility as to choice of equipment and adaptation of the ventilation to the different techniques of the drill & blast cycle, while improving the work environment and the documentation thereof.

The fan control and reduced duct friction would reduce power costs. More importance was put on the possibility to achieve an improved work environment.

The project utilised as test arena the 4.2km long Sveio drive of the 7.8km long Bømlafjord subsea road tunnel on the southwest coast of Norway. The tunnel cross section is 80m^2 and the maximum grade is 8.5%. The lowest point is 260m below the sea level and the total climb from the lowest point to the Sveio portal is approx. 300m.

In order to reduce the toxic fumes, emulsion explosives were used, with an expectation of emissions of 1/25 of NO_2 and 2/3 of CO as compared to ANFO. An electric Brøyt 70 ton excavator was used for loading; the shotcreting jumbo was also electric. The main contributors to the pollution of the tunnel air was the 35 tons dump trucks (up to 13 units) hauling the muck up the long steep grade at low gear.

The ventilation was supplied by two AL 17, 250kW fans blowing through two 2.0m diameter ducts. Due to the spread pollution from the trucks, high capacity blowing ventilation was considered suitable: the capacity was 100m^3 per second.

The control system recorded measurements of gas (NO_2 and CO) content in the tunnel and air pressure and velocity at the tunnel face and at the portal. The effect of the fans were controlled by a Programmable Logic Controller located outside the portal.

The recording units for gas were electro-chemical sensors placed in a container equipped with radio connected to a slave computer 150-600m from the face and 150m into the tunnel (in a cabinet). The recorded data were transferred (UHF low band) to the main PLC; a radio link boosted the transfer when the drive got longer than 2km. The main PLC was connected to a computer in the site office for logging and display of all measurements and events, as well as alarm picture, fans control parameters and trend diagrams. A number of manual radios were also provided, which allowed the crew to over-rule the automatics and control the fans manually.

After the initial development and testing of the prototype recording and control system, it was installed in the tunnel, which at that time had been driven 3km of the 4.2km drive. Because of this, only part of the potential for power cost savings were realised; ~ 35,000 USD per year against the full potential of ~ 85,000 USD per year.

The other experiences were positive:
- the handheld radios (manual controllers) worked well in the tunnel environment;
- the electro-chemical sensors in the container (installed outside the container) and in the cabinet (in the tunnel) showed reasonable correlation to handheld sensors for CO, but with relatively large differences for the NO_2 measurements. The latter, however, being in the range of fractions of one ppm.

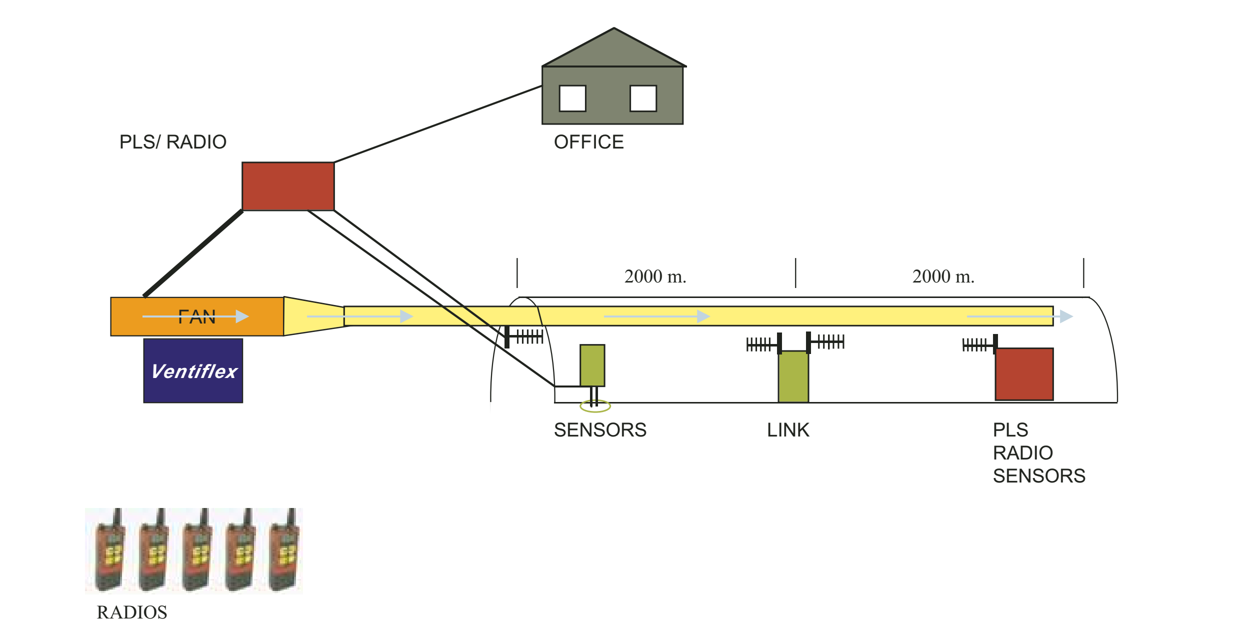

Figure 3: Overview of the Intelligent Tunnel Ventilation system

The results regarding air quality at the face showed that:
- the NO_2 concentration was hardly measurable;
- CO from the blasting fumes was evacuated fast;
- CO concentration during scaling from the muck pile was too high;
- CO concentration inside the loader's cabin was too high;
- Uncomfortable draft was experienced due to the high volumes of air;
- Dust from mechanical scaling and shotcreting was not diluted sufficiently.

The results regarding the air quality throughout the tunnel indicated:
- Generally good air quality, but not suitable for other works until 1 hour after muck transport is completed;
- NO_2 concentration was too high in the outer kilometre of tunnel drive due to the dumper trucks;
- CO from the blasting fumes high
- Measurements inside the dump truck cabins showed concentrations below the norms.

Measurements were also performed at face for NO, but no detectable values were recorded.

New duct material with significantly reduced expansion under high pressure was developed. The development of a new jointing system for the ducts was postponed for further development by Protan AS after the project.

The equipment for fan control was re-used in the Baneheia road tunnels in Kristiansand in southern Norway

3.2 Bragernes tunnel

In the Bragernes tunnel near Oslo, a measuring station for dust, CO and NO_2 was installed. Similar results as in the Bømlafjord tunnel were observed:
- The CO concentration from the blasting fumes was high for a short while;
- The NO_2 concentration increased over several hours during loading and muck transport.

The fan was kept running at full speed most if the time hence the power saving potential was not realised.

3.3 Main conclusions

The tests in 2 tunnels confirmed (Lima, 2001):
- The system functions robustly;
- The control of fans with manual radios works well;
- The documentation of the air quality with focus on measurements increases the consciousness about air quality and health;
- It is possible to reduce the electric power consumption; the full potential may be realised as the attitude towards more "conscious" control of the fans will increase.

4 CONCLUDING REMARKS

Improvement is possible:
- Mobile (hand-carried) gas sensors should be connected to the data base, providing a more complete picture and documentation of the work environment at different locations in the tunnel;
- A more extensive measurement scheme for duct pressure will provide a better monitoring of duct condition and need for maintenance;
- More information is needed to encourage others to look beyond the initial high investment costs towards the long term benefits of better work environment and potential for reduced power costs;
- The occasional use of "old machines" (loaders, dump trucks) may undermine the overall efforts and should be abandoned;
- The use of diesel engines with particulate filters to be considered

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8. AUTOMATIC CHARGING OF EMULSION EXPLOSIVES TO INCREASE SAFETY, PRODUCTIVITY AND QUALITY

Randi Hermann, Mesta as
Jan Elvøy, Mesta as

Summary
A joint venture (JV) of Mesta AS (formerly the Production Division in The Norwegian Public Roads Administration), Skanska Norge (previously Selmer Skanska AS), Bever Control AS, and Dyno Nobel AS has since May 1997 developed an automatic charging system for emulsion explosives suitable for tunnelling. The main targets was to reduce the time consumption for drilling and charging by approx. 20 % while improving work safety. The charging system eliminates human activity in front of the drill jumbo during drilling, adhering to the new regulations. The JV completed a feasibility study (1997) followed by a research program (1998- 2000) The prototype was completed 2003.

The charging system is mounted on a separate boom on the drill jumbo, and consists of a charging manipulator, a charging tube for inserting the primer and charging hose, as well as a system for transporting the primer. A vision system is used for the recognition of drilled holes and fine positioning of the charging tube. The system was tested and presented in a demonstration at the tunnel project Baneheia in Kristiansand, Norway in May 2001. The manipulator could operate the system over the complete face, remote controlled from the cabin. The results were promising, and the JV concluded that a commercial system is feasible. Later engineering and construction of the system took place and was finished summer of 2003 and tested during the fall of 2003. Mesta AS has purchased the first complete charging system which is now installed on one of the drilling jumbos owned by the company.

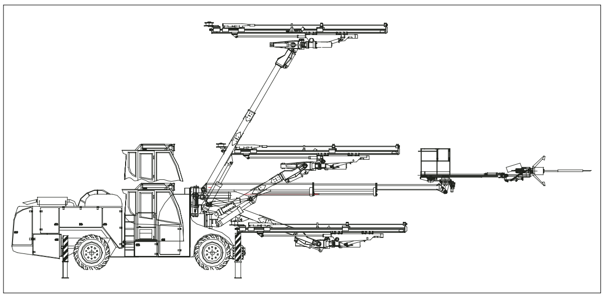

Figure 1 Automatic explosive charging system mounted on a fully computerised AMV drill jumbo.

1 BACKGROUND
The purpose of the project was to investigate the possibilities for automatic charging of blast holes in tunnels. The background for this was, among other things, a conversion to the use of emulsion explosives, as well as adaptation to new regulations that prohibits simultaneous manual charging and drilling on one of the tunnel face.

The main target of the project is to automate the charging in tunnelling in order to reduce the time consumption for drilling and charging including the connection of the detonators by approximately 20 %. Through an automation of the charging process, human activity in front of the drill jumbo during drilling will be eliminated during drilling in accordance with the new regulations.

Subcontractors for the project were Bamble Mekaniske Industri *(mechanical industry),* Andersen Mek. Verksted *(tunnelling machinery and equipment manufacturer),* and SINTEF Elektronikk og Kybernetikk *(electronics and cybernetics).*

2 INCREASED SAFETY ON FACE DURING CHARGING
Today, charging is done manually on face after drilling is completed in line with the new regulations. Block falls and slabbing rock on face represent a risk of injuries and damage during charging. The handling of explosives also represents a risk.

Rock drilling during tunnelling is to a large extent an automated process in Norway. The drill jumbos of this generation are equipped with computer programs in which the drill plan is preprogrammed. As an advance-

Figure 2 Manual charging on face

ment of the automated drilling, computer technology is used to develop an automated charging process. Such products are not available on the current market. The technology enables drilling and charging at the same time within existing laws and regulations.

Automation of the charging process will eliminate personnel from staying between face and the rock drill jumbo; thus, reducing the risk of accidents considerably. The social consequences and costs connected to such work can be strongly reduced.

In addition to increased safety by eliminating personnel on face, the system also has a number of other advantages in relation to security and quality. A charging log is produced based on the charging. For the operator on face, the display will appear as shown in Figure 3 (still undergoing development). There, the driller will have access to information concerning the charging at all times. The charging may be managed manually or automatically (according to a pre-programmed charging sequence). An operating panel with joy sticks allows for overriding during automatic mode.

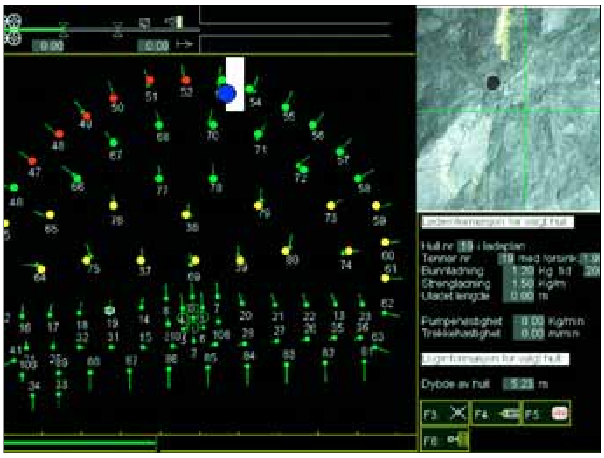

Figure 3 Display from operator's screen. Prototype. Shows loaded holes and position of charging hose. The top left shows a picture of drill holes on face. Below on the right, selected data from the charging are shown.

Requirements for safety distance in the new regulation in terms of distance from the drill and loaded hole are taken care of in the control system. This appears for the driller on the screen as colour coding and symbols, se Figure 3. A yellow symbol indicates drilled holes, whereas a green symbol indicates all holes that have been drilled and lie far enough away to be loaded (i.e. 2 m). Loaded holes are marked with a red symbol, while non-loaded holes are marked with smaller, green symbols. On the top right, the status for the insertion of the charging hose can be seen.

The charging log provides a quality improvement compared to today's charging process. The system gives more accurate information of amounts of explosives per hole. This may be used for vibration control during blasting in urban areas.

In connection with the construction of this feeding apparatus, a need arose to make a new type of primer. This primer is going to be fit especially to the system, and may allow for a safer charging of problem holes. Designing a new primer makes it possible to pull it out again if problems arise during charging. This implies a clear benefit in terms of safety.

3 FEASIBILITY STUDY AND RESEARCH PROGRAM

3.1 Technical tasks

Three main technical tasks were defined (1997):
1. Recognising a drilled hole and guiding the charging hose into the hole in a controlled manner
2. Inserting the correct detonator and primer into the drill hole
3. Controlled charging of the hole using the proper explosives

The team agreed that the feasibility study (1997 – 1998) would focus on item 1. A prototype system was built. This consisted of cameras, illumination, and computer hardware to provide a technical solution for the purpose of demonstration. The feasibility study concluded that further development could be based on the methods tried out in the feasibility study.

The feasibility study was continued in a research programme from 1998-2000, supported by NFR (The Research Council of Norway).

3.2 Results – developing equipment for prototype

The design of a prototype was completed at the end of 2000. The prototype consisted of a camera, charging tube, hose feeder, charging manipulator, and ancillary control system. The prototype was tested in an AMV workshop in January 2001 against a simulated face, i.e. a wooden wall with drill holes. A measuring system has been developed based on the use of a video camera and data processing in order to recognise and measure positions for drill holes on face.

The charging boom is operated automatically close to the blast hole. The charging tube is oriented in the proper direction based on data from the drilling log. This is possible with the help of sensors in the boom's links and a geometry model of the boom. Through the positioning based on the drilling log, the tip of the charging tube is

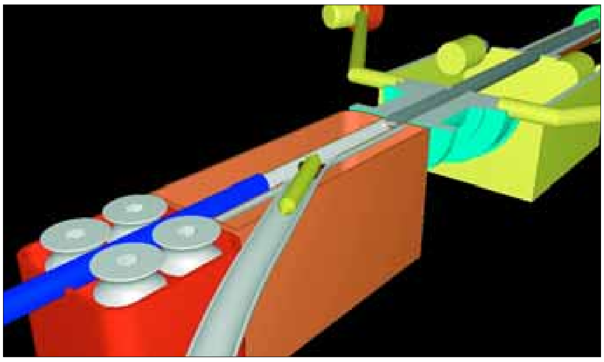

Figure 4: Feeder system for charging hose and primer, illumination, vision system, and charging tube.

Figure 5: Manual charging station, prototype. Later, operation of the hose feeder will be integrated with a control system for the boom. The feeding position is located at the boom mount on the drill jumbo.

brought closer to the blast hole, but not sufficiently accurate to allow the charging hose to enter the blast hole. Based on data from the vision system, the charging tube may be moved with sufficient accuracy to guide the charging hose into the hole.

A separate charging manipulator has been developed. This is mounted on one of the drilling booms used in the experiment A charging tube is mounted at the front of the manipulator. This has a hose feeder for insertion of the charging hose with detonator and primer into the drill hole. The manipulator is moved close to the drill hole that is to be loaded. A primer with the proper detonator number is inserted into the hose feeder with a pneumatic dispatch from an operator's console at the back, close to the drill jumbo, see Figure 5.

The detonator is automatically inserted into the front part of the charging hose. Subsequently, the charging hose is guided through the charging tube and into the blast hole. When the hose has been guided to the bottom of the hole, the pumping of the emulsion explosive begins. This causes the primer to be pressed out of the charging hose, after which the hose is pulled backwards with a controlled speed until the emulsion string has reached its proper length.

4 INDUSTRIAL PROTOTYPE – COMPLETE CHARGING SYSTEM

4.1 Project continuation

In the middle of November 2000, the JV received positive feedback from SND (The Norwegian Industrial and Regional Development Fund) with an offer of financial support for the project. Thus, the project continued in 2001 – 2003. The aim was to construct an industrial prototype.

4.2 Charging tube with vision system is positioned by the blast hole

A charging tube with a vision system and other sensors has been designed and built. The charging tube is mounted at the front of the manipulator's boom in front of the charger. In principle, the cameras only measure angles between the charging tube and various holes on the side of the charging tube. In order to facilitate the search for holes and to be able to calculate distances to the face, a range finder is mounted in the camera body. This continuously measures the distance from the cameras to the face.

4.3 Feeding of primer in an air hose and emulsion through charging hose

Alternative principles for guiding primer and detonator safely and reliably through a charging hose have been studied and tested. The detonator number for the individual drill hole cannot be planned in advance; thus, it has been decided that the detonator and primer must be guided into the system manually by an operator who must be behind the boom mounts on the drill jumbo. A hose feeder for the charging hose has been constructed, built, and tested. It can be mounted on the manipulator's boom right behind the charging tube and the vision system. See figures 4 and 5. The hose feeder possesses actuating drives and sensors. This enables it to control and monitor correct insertion of the primer at the front of the charging hose and that the hose is guided to the bottom of the blast hole prior to dispatching of primer and detonator and pumping of emulsion explosive.

A control system for the charger has been developed, built, and tested. This system enables automatic charging of the blast hole.

4.4 Charging with emulsion explosives

An important condition for automating charging at the tunnel face is the use of only one explosive. In other words, the explosive must cover the needs of cut holes, enlargement holes, contour holes and 'lifters' alike. The first condition is that it must be water resistant. Secondly, it must be possible to vary the blasting strength in the various groups of holes. These demands can be met by using a pumpable emulsion explosive. By varying the degree of filling in the individual blast holes using 'string charge', a controllable charge per metre of drill hole is achieved. In short, the emulsion explosive is pumped into the drill hole with a given capacity of e.g. 40 kg/min. By pulling the hose out at a constant speed, a well-defined 'string' of explosive will remain in the blast hole. By varying the pull-out speed, the fill-up level will vary accordingly. See Figure 6 for string from experiment in the Baneheia tunnel in the spring of 2001. The present system makes it possible to vary the blasting strength from 100% filling down to 0.35 kg/metre drill hole.

4.5 System for remote control of the entire charging process

A control system for the manipulator's boom and the charger has been developed and built. All 8 links in the charging boom/manipulator are equipped with instruments containing angle sensors or devices for measuring length in the same way as on the drilling booms. In this part of the project, however, only the five links in the manipulator have automatic control for fine positioning according to data from the cameras. The system PC has programs for the superior control of the system. It has a screen that normally shows the drilling log to be used during charging, see figure 3.

Figure 6: String of explosive. Tested in plexiglass pipes

5 FULL-SCALE TESTING

In May 2001, a full-scale test was carried out for automatic charging of an AMV rig at the Norwegian Public Roads Administration's tunnel production plant in Baneheia, Kristiansand. The test comprised:

- Positioning of charging tube for automatic and manual insertion of charging hose;
- Feeding of primer to charging tube;
- Feeding of charging hose with primer and detonator in drill hole;
- Charging of emulsion explosives with controlled withdrawal of feeding hose;
- Charging cycle was carried out with dummy primer and emulsion explosives in non-gassed and gassed condition. A complete test of the charging cycle was carried out.

The test took place in a pilot tunnel on an extremely angled face. The testing included charging of holes:

- placed completely towards contour;
- on extremely angular planes;
- that were placed behind an overhang – and were therefore concealed from direct view;
- made accessible with the help of projecting plastic pipes (for lifters etc).

The experiments on the tunnel face gave experience with conditions that can normally be anticipated.

6 PROGRESS SCHEDULE

Mesta entered into an agreement with Bever Control and AMV as system suppliers, and with its JV-partners regarding the purchase of one complete charging unit.
AMV designed and built the prototype that was completed in the 2003. In the fall of 2003, the first test of the prototype took place and the development project was completed. Later the charging system was temporarily installed on a computerised drill jumbo operated by Mesta to gain further experience using the system in ordinary tunnelling.

7 CONCLUSION – FUTURE TASKS

The project has given positive results. Based on results so far, the system - in the opinion of the project group - the system has the potential to become a viable commercial charging system.

During operation so far, however, it seems necessary to develop other elements of the charging process to be able to remove crew completely from the tunnel face.
Remaining unsolved items for full automation are:

- Automated interconnection of the detonators;
- Dealing with clogged or partially clogged holes

The greatest challenge in achieving a complete automated system is connected to the selection of the numbered detonators for the individual holes and the coupling of the detonators. Electronic detonators will be advantageous. When the explosives industry some day can supply cordless electronic detonators, all-automated charging at face may become a reality.

Figure 7: Automatic charging, the Baneheia tunnel, 2001.

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9 DIESEL UNDERGROUND, PROJECT RESULTS AND RECOMMENDATIONS

Jarle Gausen, Skanska Norge AS

1. BACKGROUND

The project "Diesel Underground" was initiated through The Norwegian Tunnelling Society (NFF) Development Committee in the year 2000. The object of the feasibility study (autumn 2000 – summer 2001) has been to define state-of-the-art, prioritise areas for study, and organise a main development project on the use of diesel in underground, focusing on technical solutions and recommendations. The aim was to clarify the health-related consequences of the use of diesel for underground construction work and to propose measures that would reduce the hazards for the work environment.

The background for this project was the attention given to health damage caused by diesel waste gas (exhaust) in tunnels and mines. The report "Exposure and obstructive pulmonary disease in tunnel workers - an epidemiological study" (Ulvestad et al 2000) especially expressed the dangers of inhaling diesel exhaust. This triggered the effort for improvement.

The feasibility study was organised with one steering committee and three working groups that reported to the steering committee.

In order to cover the broad subject area, the group covered all related disciplinas. The project group had members from the Norwegian tunnel- and mining industry. The steering committee and working groups consisted of representatives from The Norwegian Public Roads Administration, the contractors Selmer Skanska and Scandinavian Rock Group, The Norwegian Construction Industry Association (BNL), SINTEF, The Norwegian Labour Inspection Authority, and The Norwegian Petroleum Institute.

Fig 1: The diesel exhaust may cause health hazards

2 RECOMMENDATION FROM THE STEERING COMMITTEE

According to the findings of the working groups, the steering committee concluded with some specific short-term and long-term measures that will improve the working environment when implemented. Additionally, areas that need more long-term work in order to achieve further improvements have been pointed out. The report from the feasibility study can be downloaded from www.tunnel.no (see references)

2.1. Specific measures

Diesel quality

The best diesel quality currently available provides the basis to obtain the best possible work environment. The diesel with the lowest sulphur content must be chosen! This can be achieved through:

- ***The industry (contractors):*** By using low-sulphur diesel for all underground vehicles.
- ***The builders (owners):*** Through a revision of the Owner's Regulation (which outlines the Owner's overall responsibility for HSE, Regulation No. 534) that requires the use of low-sulphur diesel for all underground works. The Owner's HSE-plan should contain a requirement for a maximum sulphur content of 50 PPM in diesel used underground (present requirement is max. 500 PPM).
- ***The Norwegian Labour Inspection Authority:*** Revised regulations from this authority have resulted in very strict requirements (found in the new attachment VIII, Machine Regulation, No. 522). It will not be possible for the industry to fulfil these requirements unless diesel containing a lower sulphur content is used. Thus, the steering committee suggests that the Rockwork Regulation (No. 547) must include a requirement of a maximum sulphur content of 50 PPM for diesel used below ground.

- ***The public authorities:*** Stimulating increased use of low sulphur diesel through tax refund. A part refund system has been introduced, but should be co-ordinated.

Particulate filters
A reduced content of sulphur opens possibilities for the use of new cleaning technology, e.g. particulate filters. Testing of available cleaning equipment (including catalytic) have been performed as part of the project.

It is the opinion of the steering committee that, even though there are not adequate measuring methods for soot and particles, requirements concerning the use of particulate filter should be introduced. Since the measuring technique is undergoing rapid development, it is difficult to specify the type of particulate filter. A particulate filter must be chosen according to the class of machinery and task. When the practical conditions connected to the use of particulate filters have been clarified, the steering committee wishes to include requirements for particulate filters below ground in the Rockwork Regulation (No. 547). Further work with particulate filters, including full-scale testing, will be an important part of the main project.

2.2. Long-term measures and tasks
Information, attitudes, behaviour and motivation:
In the effort to reduce exposure to diesel exhaust below ground emphasis should be placed on information, attitudes, behaviour, and motivation for all parties involved: the contractors, the owners and the supervisory authorities. The work must be directed both towards the management and the individual employee.

Measuring methods for gas, dust, and soot
It is particularly important to be able to measure the effect of measures when these are implemented. According to the working group, the current measuring methods for diesel exhaust are not good enough. In addition to improving the methods for measuring gas and dust in the working atmosphere, further work must be undertaken with joint measuring techniques and techniques of analysing diesel exhaust. If requirements related to soot in the working atmosphere shall be introduced, new measuring techniques must be developed.

Permanent electric supply installed in the construction phase
In some tunnels (e.g. road tunnels) it may be possible to installing the permanent electric supply at an early stage during construction. This will provide the opportunity for electric drive of several machines in the completion phase. The conclusion of the work group is that a full-scale experiment should be carried out in which permanent electric supply is laid during the excavation phase. To achieve this, it is important that electrical machines and equipment adapted to tunnel operation be further developed.

Equipment
Thorough assessment of the choice of machines and equipment adapted to the specific project is crucial. Equipment must be optimised to suit the work environment!

3 FURTHER WORK IN THE COOPERATION PROJECT

The main development project "Diesel powered construction underground" was started in June 2002. The objective is to continue the work of the feasibility study. Again, three work groups have been established:

- Diesel quality
- Cleaning techniques
- Relations to the authorities

The purpose with the project is to contribute to the reduction of the exposure for underground construction workers to diesel exhaust. This will be achieved by:
- Use the best available diesel motors
- Use the best available diesel quality
- Use the best available cleaning techniques for the exhaust

The objectives through the working groups are:
- Clarify the influence of the diesel quality and any additives on the exhaust
- Document the effects of the different cleaning techniques
- Assess the suitability of the present regulations, requirements, and the practical measurement techniques available
- Inform the industry about achieved results

The results of the project shall be:
- Propose improvements of regulations, standards and requirements
- Create attitudes in the industry towards improvements of the underground work environment
- Influence decision takers, including at the owners, to work towards measures that will improve the work environment

A steering committee is responsible for the progress. It has a wide participation with representatives from the Norwegian Public Roads Administration, the contractors Mesta, Veidekke and Skanska Norway, the Norwegian Union of Construction Workers, SINTEF, Norcem, the Norwegian Labour Inspection Authority, and the Norwegian Petroleum Institute.

The working groups have members from the same organisations, plus from Altima.

Preliminary field studies have been performed for testing of one type of particulate filters, by M. Sc. thesis work at the Norwegian University of Science and Technology, Department of Construction Engineering. Further testing including several filter types and diesel qualities are under preparation at SINTEF, Trondheim.

The plan is to complete the project by end of 2004.

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- Underground facilities

Excavation work in the Gjøvik Olympic Mountain Hall, which was ice-hockey arena during the 1994 Olympic Winter Games in Lillehammer, Norway. This is the world's largest public mountain hall.

A shotcrete robot working its way through the Norwegian mountains.

10 WORKING CONDITIONS BEHIND THE TUNNEL FACE – CHALLENGES CALLING FOR NEW SOLUTIONS

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Anders Beitnes, SINTEF Civil and Environmental Engineering
Nils M Beitnes, Scandinavian Rock Group, SRG

1 INTRODUCTION

Norway is building 20 – 40 km each year of drill & blast tunnel for infrastructure, mostly single tube tunnels for roads or railways. Such tunnels will constitute a major part of the tunnelling in many years to come.

Due to the continued demand for reduction of total construction time, there is a strong incitement to start installation and completion works before excavation breakthrough and to finalise the tunnel as early as possible. This is especially the case for longer tunnels. The demands in this respect stem from the Owner (who benefits from early start of operation), but also from the Contractor (who may benefit from a connected reduction of overhead costs, improved cash-flow etc).

This situation has created a dilemma with respect to quality of works, work safety and work environment. Some unfortunate incidents in recent tunnelling projects have been assessed to stem from too strong emphasis on rapid excavation and completion. Examples include excessive ground water drainage due to insufficient pre-excavation grouting and rock-fall incidents due to poor adaptation of rock reinforcement.

This paper address the effects on work safety and work environment resulting from efforts to reduce construction time. A look at the state-of-the-art of organisation of tunnelling works and suggestions for new approach to improvements are included.

2 THE CHALLENGES

Performing completion works while still excavating may introduce difficult working conditions in the sections "behind" the tunnel face. "Behind face" is an expression frequently used for contractual matters, then referring to work activities that are not taking place at the tunnel face or affecting the critical path of tunnel face advance (such as probing, pre-excavation grouting, excavation and primary rock support).

In this paper we are concerned about the tunnel sections where work take place outside the area supplied with fresh air from the main ventilation duct, which is most often limited to the 100m closest to the advancing face. Typical works that are carried out in these sections are (or may be): installation of drainage pipes and basins, road substructure and roadway (or equivalent for railways), supplementary (permanent) rock support, water shielding and frost insulation, lining (rarely), cable ducts, sub-stations for power and control, lighting, safety equipment, concrete portals etc. In the following the tunnel sections where such works take place are referred to as the "rear section" of the tunnel.

The challenges are in the following expressed as problems that must be solved.

2.1 Adverse working conditions due to dust and gases

Normally, the ventilation forces fresh air via ducts to the tunnel face. During ventilation of the blasting gases and during loading and transporting of the tunnel muck by diesel powered rubber wheeled equipment it is almost impossible to sustain acceptable working conditions in the *rear section.* The levels of gas (NOx, CO etc) and dust may easily exceed the "administrative norms". However, these difficult conditions are typically lasting only some 2 hours after each blasting round. The rest of the time of each work cycle (during probe drilling, pre-grouting, rock support, blast hole drilling, charging) the working conditions in the *rear section* are less strained, and could probably be improved to be more efficiently exploited. The potential is particularly large during phases of extensive pre-grouting and heavy rock support, which usually result in spare capacity for machines and equipment.

2.2 Hazards of mixing wheeled transport and roadside work

This is primarily a problem during mucking out. According to Norwegian practise, the transport is most often performed by sub-contractors, who usually are bound by strict time limits for completion of the transport for each blasting round. This practise may not be a good combination with roadside works in the *rear section,* due to possibly high driving speed, insufficient light, bumpy and wet roadway, overloaded vehicles etc. This may increase the risk of collisions and accidents, and cause unpleasant working conditions not conducive for performing high quality construction works. Besides, there always has to be a free, driveable passage out of the tunnel for evacuation purposes, which may hamper the work in the *rear section.*

2.3 Services infrastructure does limit full access for installation works

During excavation, there is a need for uninterrupted supply of power, water, fresh air to and drainage from the tunnel face. Completion works in the *rear section* with today's solutions will obviously be hampered and possibly limited in extent because of the presence of high voltage cables, water pipes and air ducts, and their supports. Connected risks are not only interruptions in services and resulting and hazard at the tunnel face, but also for example short circuits (which may trigger explosions or fires) and leakages which could cause accidents, damage equipment, installations and civil works. At the same time, the services infrastructure for the tunnel face works are poorly suited for supplying the works in the *rear section.* Tools may have to be powered by diesel engines and there may be a lack of electric light and suitable water taps.

Introduction of a conveyor belt used for muck transport will have positive effect on the working environment in the *rear section.* It may, however, either roof or sidewall mounted, introduce even stronger restraints to completion works in the *rear section* due to the reduced access to the respective parts of the contour.

2.4 Strained logistic for completion works after break-through

For reasons discussed above, completion works during face advance are often to a large degree found impractical. Instead, there is typically a strong demand for numerous activities to be performed at the same time and at a number of locations along the tunnel *after* break-through. For example, this may include supplementary rock support, exchange of sub-base material, road building, pipe –works, foundations of structures and concrete works at the portals. As these work activities advance along the tunnel, new activities will start behind them, such as lining, road completion and the electrical and mechanical installations. In longer tunnels one may end up having almost finished the completion works in one end of the tunnel, while performing rock support in the other end. This makes it difficult to plan and execute the various activities, as they to a large degree obstruct free passage for each other. The potential conflicts may cause unwanted incidents.

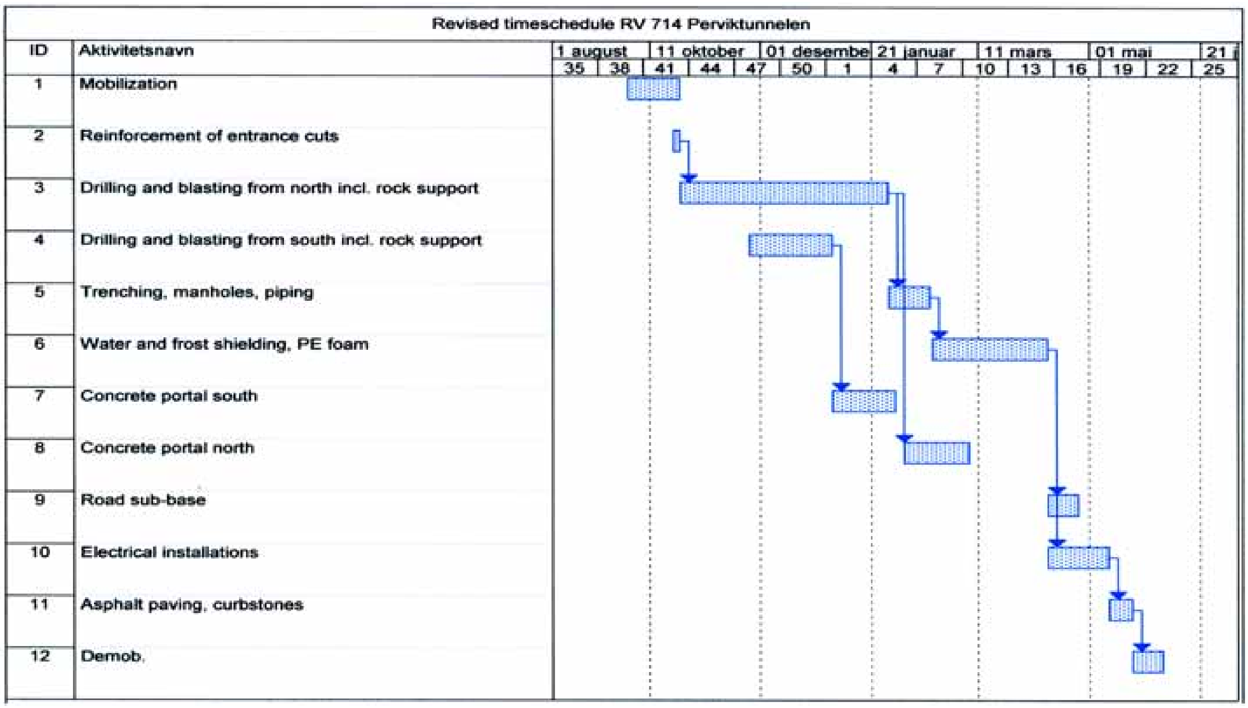

Fig 1. Example of time schedule for completion works – Rv4 Gjelleråsen – Slattum

2.5 Conditions after break-through are subject to frost and wind

This is especially true during winter, when cold draft through the tunnel can cause problems. During construction of the 3.4 km single tube road tunnel at Gjelleråsen near Oslo, build-up of ice was experienced in areas with water ingress, both in the roof and in the floor. This made it hazardous due to risk of falling ice, and removal of the ice by machinery became necessary. Frost also made it difficult to perform shotcreting, concrete works, road building and so on. It is often necessary to install gates to close the tunnel portal and thereby stopping the draft. But by doing so, one may significantly worsen the working environment in the tunnel, because the gates hamper the ventilation.

2.6 Difficulties in distributing fresh air to multiple work areas after break- through

After break-through, a lack of forced ventilation makes good weather conditions crucial in order to maintain a draft trough the tunnel. But in unfavourable weather conditions, or in periods with frost, the natural draft may be non-existent. There are numerous examples of working conditions rapidly turning so bad that work has to be stopped and resumed only when the tunnel is sufficiently ventilated. The reasons for this are often extensive engine loads (lorries, dozers etc), or for example asphalting works during roadway building.

2.7 Installation sub-contractors may be less experienced in working in tunnels

Because of the limited working space, all workers in a tunnel have to be extremely flexible and have a positive attitude to co-operation. Lack of experience may cause a lower dedication to cope with the special conditions and potential conflicts of interest. Problems may occur when inexperienced sub-contractors do not take this into consideration when planning the job, ending up unrealistically demanding "right of way" and priority for their own work all the time.

2.8 Lack of health follow-up programs for installation workers

The installation crews are not dedicated to tunnel work only. They are normally involved in a variety of tasks and working conditions on different sites (not all tunnel sites), which may result in that they fall outside systematic health monitoring programs specific for the tunnel conditions.

2.9 Too much focus on advance rates

To put the observed problems in perspective, we find it necessary to point out: Too often productivity is measured in advance rates. But productivity is more than that. In a typical road tunnel, even in fair rock conditions, excavation may represent less than 30% of the total investment. Improving the health and safety of the work environment for other work activities than just excavation will also improve productivity for the project as a whole. To obtain this, it is probably necessary to shift focus away from just advance rates during excavation, and to take a more complete view on the tunnelling process.

3 POSSIBILITIES WITH TODAY'S SOLUTIONS

When taking the challenges discussed above up for serious consideration, we have recognised that it is time to look for alternative approaches to safe, healthy and still cost efficient tunnel construction. Safe and healthy work conditions for the different crews should be a first priority. However, we anticipate that quality of works and utilisation of resources also will benefit to a large extent. The main approach will be to include a larger portion of tunnel completion works within the workspace close to the tunnel face, utilising both the available fresh air and services infrastructure in this area as well as industrialised work procedures.

3.1 Improved work zone close to the tunnel face

A considerable and well-suited work zone for completion works could be arranged within the fresh air zone (some 100-150m from the tunnel face) except during blasting and mucking out, which lasts only ~ 2 hours of each cycle. More works could then be performed in this area, provided some minor adjustments utilising available technology and resources are implemented:

- Supplementary booster for locally extended ventilation during mucking out may allow the front end of the main ventilation duct to be retracted further away from the face.
- Excellent surveying and positioning (by twin laser) is already used for programmed or semi-automatic drilling and accurate contour profiling. These facilities could be utilised for installation of pipes, ducts etc, and for road work and foundations, as well as for improved mapping and documentation.
- Automatic cleaning stations for vehicles are state of the art requirement in certain environments and could be introduced inside tunnels close to the face.
- Mobile extensions for services infrastructure may allow unrestricted work along walls and provide power supply for tools, good light, water supply and removal of mud.
- Competent and all time present engineering geological follow-up at the site, adapting permanent rock support in close and efficient interaction with contractor’s foreman, thus allowing an efficient decision process.

The types of works that could be completed in this working area, and the benefits thereof, would be:

- Primary and permanent rock support could be performed in one operation (or within closest 15 m to the face). This will favour both safety for tunnel workers and quality of the works. There is a large potential for improved quality in rock support when performed at the tunnel face, due to improvements in surveying/positioning and fresh/clean rock surface. In general, this is also where we find the best qualified crew and the best machinery.
- Road works, such as exchange of weak rock debris, infill of graded sub-base, and introducing a reinforced concrete roadway for construction phase loads. Improved roadway quality reduces wear of equipment and clean vehicles facilitate direct transport routes from the tunnel to the permanent dump site via public roads. There is also a potential for savings when the road base can be built from tunnel rock. The quality requirement for the substructure can be optimised taking the actual rock type into account. The quality of the roadway will have to be assured by processing of the muck, which may be arranged locally. One idea is to extract sufficiently strong rock material by retrieving only the larger size fractions and use those for crushing and a new sieving process. A mobile ramp could be used to protect the front of the roadway. A necessary part of this concept would be to introduce collection of discharge water at the face even in uphill tunnelling. Thus only clean water enters the drainage ditches in the *rear section.* Pipes, ducts and lining foundations may be built into this concrete roadway as well. Permanent drainage will maintain an unsaturated road substructure and drainage basins will act as sand traps for the often occurring surplus of fines throughout the construction period. Lining foundations, where continuous, will provide excellent protection for e.g. high voltage and communication cables.
- Installation of cable trays and certain cables. By having qualified installation specialists (electricians, plumbers) joining the main contractor's team, they can serve both the tunnelling service infrastructure and the final installation works.

Probably, some interesting possibilities may follow:

- ample and fixed cycle periods (except in situations demanding extensive pre-grouting and rock support), e.g. no more than two rounds per 24 hours;
- work arranged in two shifts;
- a gap in the scheduled working hours for those not active during blasting and mucking; and
- scheduled hours for specialist services (e.g. inspections by engineering geologist)

This may give a time buffer in situations of favourable rock conditions, which should be balanced by more completion works. In other cases, face advance of critical work activities may consume most of the spare capacity and space. A net advance of 50 m/week including a high degree of completion close to the tunnel face should be within reasonable reach. In built-up areas, there may be a requirement to regulate the blasting time to ease the impact on the public, which by this approach can be accommodated.

4 NEW PRINCIPLES AND SOLUTIONS?

We would also like to introduce some thoughts about methods and solutions which are new to the tunnelling business and to discuss whether benefits could be achieved that way.

4.1 New drainage and roadway sub-base design suited for the loads during excavation

One challenge in tunnel construction is to obtain a durable permanent drainage that will collect and transport water from: groundwater ingress directly to the invert or to other parts of the tunnel contour, as well as construction water. The sub-base, which normally is made of remaining blast round debris, often becomes impermeable due to produced fines. Especially the transversal drainage needs attention and most often this is solved by introducing cross-ditches with pipes and protection layers. This results in an inconvenient interruption of the tunnelling. Use of graded material in the sub-base and a cleaner environment during mucking out could help. Other solutions could be considered, like pre-cast, multilayer concrete slabs containing permeable layers and drainage ducts. For shorter tunnels, extension of the depth of the blasted zone (blasted, but not removed rock, no pipes) have been found to work, possibly restricted to fairly strong rock types. Solutions along these lines could contribute to the relief of the inconvenient trench excavation, base material replacement and pipe laying, which may cause safety and health problems.

4.2 New solution for cast-in-place or pre-cast wall base or roadside structure

Concrete segments or 'slabs' may be designed for construction/mounting close to the tunnel face and could serve as multifunctional structures including gutter, drainage inspection, frost insulation, lining base, cable ducts and safety installations. One purpose would be to carry the construction services infrastructure like cables and water. Early mounting of such structures can also allow for rapid and unobstructed installation of final wall lining segments.

4.3 Dual function of cables

High voltage main supplies, communication and control cables for permanent operation may, under favourable conditions, be installed to serve also during the construction phase.

4.4 New types of machinery

The above suggestions may call for new types of machinery to be developed and introduced. Such development should have as a clear goal to accommodate safe and healthy working conditions and at the same time not restrict the full exploitation of experienced operators' skills. One example is a separate drilling jumbo (or similarly based vehicle) equipped with tools for scaling, rock bolting, shotcreting and installation. Other ideas are to combine a mobile bridge (to span over the road works front) and a turntable for lorries.

4.5 Crusher and hopper station plus conveyer as alternative to wheel transport

This is a concept which appears to have an increasing popularity in e.g. railway tunnel construction in Central Europe. The main advantage is to avoid the large amount of diesel power in tunnelling. It could be well suited also for shorter drives of single tube road tunnels, if combined with a new approach with a higher degree of completion at the tunnel face and integration with permanent foundations in a manner where the conveyer supports do not obstruct remaining completion works. One additional advantage will be protection of road works.

5 CHALLENGES

One obvious complication and challenge for the above discussed roadway approach is the unavoidable amount of sludge and wide-spread blast debris after each blasting round. Damage of structures installed too close to the face may also occur, as the throw may be difficult to control under a variety of rock mass conditions. Probably, the most widespread debris stems from blasting the early ignited sections of the blasting round (the "cut"). Shielding or damping of this "gunshot" effect may be an option.

The need for curing time of shotcrete and cast-in-place concrete before close by blasting has traditionally regarded as a potential restriction for performing high quality permanent structures close to a tunnel face. Recent studies have, however, shown that young concrete has a remarkable tolerance to strong vibrations.

A tunnel roadway dimensioned for carrying efficient mucking out lorries may appear like an over-investment compared to the dimensioning loads of public roads above ground. However, this is a matter of marginal costs versus total efficiency. If suitable rock material is available, the extra costs may be small.

As mentioned above, the proposed approach calls for skilled decisions on permanent rock support almost continuously, at least on a daily basis. Not all clients, or contractors, are ready to acknowledge the value of this effort, and it will depend on the availability of competent specialists. One further practical challenge in this principle is that groundwater ingress does not show immediately after blasting and may also change during the weeks and months after excavation. One should perhaps avoid installing the final water shielding shell close to the tunnel face, at least for the roof section. Otherwise, the result may be either an over-investment or the need for supplementary shielding later.

6 FINAL REMARK

Changes in contract conditions, as well as changes in attitude, organizing and techniques should be considered in order to substantially improve the working conditions in the *rear section* of tunnels. More emphasis must be put on other work activities than just excavation and rock support. This paper described several elements of a new approach conceived under this ambition. The most important condition is to allow for sufficient construction time. It must be a contract requirement to schedule and carry out the works in a manner that does not impose risks of compromised safety and healthy work environment.

Oslofjord strait crossing breakthrough with remains of freezing equipment

11 ELECTRONIC ACCESS MONITORING – IMPROVING TUNNELLING AND MINING SAFETY

Jan Lima, Mesta as
Svein Skeide, Road Authorities

Summary
To fulfil regulations in terms of monitoring how many people are in a tunnel or mine in case of emergency situations, an electronic access monitoring and safety system has been developed. The system consists of three main components: tags, monitoring stations and administration software.

Everyone with valid access to the tunnel is required to wear an electronic tag. If a user passes a monitoring station without, a red light will signal to the passing person that access is denied (passing done without a valid tag).

The monitoring station(s) placed at strategic points in the tunnel system. The unit will automatically submit its reading to the administration software usually situated in the manned operation office of the site management. It is also possible to establish voice communication between the site office and the monitored zone.

The administration software provides the user interface for the administrator or other users of the system. In an emergency situation, the administrator can print or display a detailed screen status report of the domain inventory, i.e. how many people are present and in which zone.

1 ESCAPE ROUTES – NORWEGIAN REGULATIONS

The basis for the development of access monitoring in tunnels and underground openings is *§30 'Fire protection and escape routes' of 'the Regulations concerning Safety, Health and Working Environment on Construction Sites'* :

§30: A system shall be established that provides a continuously updated list of which employees are underground, and their most probable location.

This requirement has its background in the scarcity of escape routes in tunnels during construction. In most tunnels there is only one way out. This may be critical in case of emergencies.

2 SIMPLE MANUAL SYSTEMS

Today, the Underground Work Regulations are satisfied by means of visitor protocols, magnetic boards or other manual systems. These may function well as long as the number of personnel is limited and the routines are regular. When several contractors and suppliers are present, partly with different work routines, the overview will easily suffer. The result may be that the monitoring routines connected to movement of personnel will not be followed.
A manual system requires strict discipline by the personnel driving in and out of the tunnel. One example: by wheel-bound muck transport the truck drivers frequently forget to register for every truckload.

If it is accepted that some workers can move in and out of the tunnel without logging, the Underground Work Regulations are not satisfied. Manual systems also do not record any unauthorised entries, which is difficult to prevent in relation to an efficient operation which demands open tunnel portals.

3 WORK GROUP FOR ASSESSING ACCESS MONITORING

The Development Committee of the Norwegian Tunnelling Society appointed in 1999 a work group with the mandate to assess the existing electronic monitoring systems and potential alternative technology. The work group consisted of participants from the major contractors Skanska Norge (Selmer Skanska), NCC, the AF-group and SRG, the Norwegian Public Roads Administration's construction division (now Mesta), and Franzefoss Bruk (an underground quarry operator).

The group established that none of the systems available in the market at that time satisfied the requirements of the industry, i.e. to monitor all personnel entering or exiting including those travelling in cars or other wheel-bound machinery.

The work group then defined the following requirements:
- the monitoring station shall read movements from personnel walking or driving by up to 80 km/hour;

- the reading capacity shall be 20 tags in a bus passing at 80 km/hour at optimal conditions.

To satisfy these requirements, the group embarked upon a co-operation with the suppliers Protan and Q-Free. Q-Free's technology for recording electronic cards was tested in a pilot project in the Bragernes tunnel in Drammen near by Oslo. In December 1999, the pilot project was concluded with a recommendation to proceed with Q-Free's technology and adapt it to use in tunnels and mines.

The pilot project lead to a public development project part financed by the Norwegian Industrial and Regional Development Fund (SND). The co-operation partners besides SND were the Public Roads Administration, Selmer, Q-Free, Protan and the Norwegian Tunnelling Society.

4 ACCESS MONITORING AND SAFETY SYSTEM FOR TUNNELS AND MINES

The development and adaptation of the technology started the fall of 2000. During the development project two pilot systems were installed: one in the Bragernes tunnel and one in the Boge tunnel (close to Bergen). The project was completed in 2002.

The project was managed by Q-Free with the Public Roads Administration, Skanska Norge and the Norwegian Tunnelling Society as contributors with respect to functional requirements, technical solutions in the tunnel and testing of the system in the two test tunnels. Q-Free performed the technical development and Protan acted as distributor of the developed products.

4.1. Description of the system

The electronic access monitoring and safety system is designed around an electronic card or chip (here called 'tag') which the workers and other personnel are wearing. The tag has its own battery and is activated by the radio beam from the monitoring station. By placing monitoring (card reading) stations at the tunnel portal and inside the tunnel, the tunnel is divided in zones. The monitoring stations record the movement of the tags from one zone to another, by the means of one radio beam pointing outwards and one inwards. The recorded movements from the different monitoring stations are collected by radio communication (Ultra High Frequency: UHF) or by cable. On a computer in the construction office, one can at any time see how many are present inside the tunnel and in which zone they are. If an accident occurs, an overview over the personnel in the different zones can be printed immediately.

The system consists of:

- Tags for all personnel working on the site, plus tags for visitors;
- Monitoring stations;
- Administration computer with software.

4.2 Increased safety for the tunnel workers

Access monitoring provides increased safety for the workers and visitors in the tunnel. In case of accidents an updated overview is immediately available. This makes it easier for rescue personnel and others to help any accident victims or trapped personnel. Especially on large and complex underground sites, such a system will provide a significant improved safety.

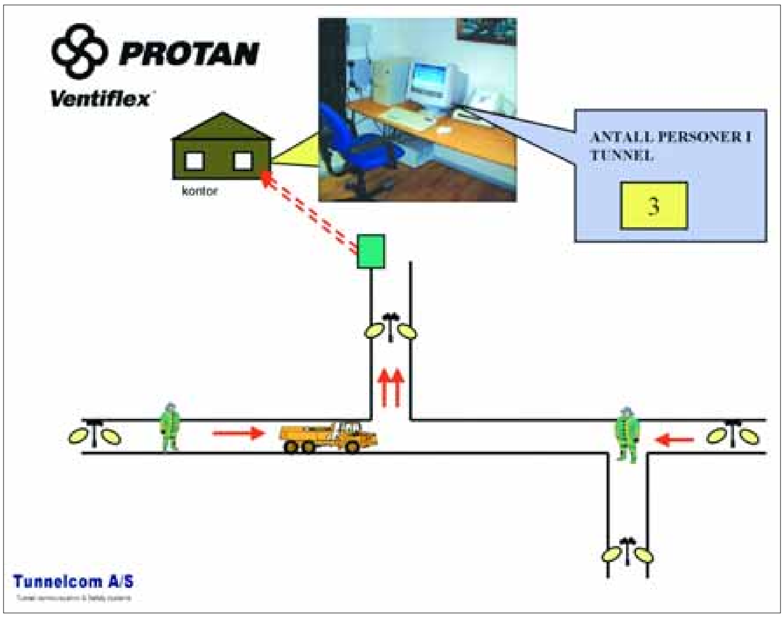

Fig. 1 Access monitoring system based on personal ID-cards (tags), monitoring stations and administrative PC at the site office. (Antall personer = number of personnel)

4.3 Practical trials
Selmer Skanska tested the system in the Bragernes tunnel the summer 2001. The Public Roads Administration tunnel construction division tested it in the Boge tunnel. The system has also been used on the Södra Länken project in Sweden, by an installation monitoring more than 30 zones.

5 USE OF THE ACCESS MONITORING SYSTEM
In order for the access monitoring system to function properly, routines have to be established for:
- Use and how to wear the tag;
- Checking and maintenance of the components;
- Use and administration of the software;
- Overview of the site zones;
- Visitors' protocol.

5.1 Use and how to wear the card
The tag shall be worn by all personnel at the site. The tag shall be placed in a breast pocket, in a special pocket on the arm or worn as a necklace. In addition to the tags for the regular personnel, a sufficient number of tags shall be available for visitors and as reserve.

5.2 Checking and maintenance of the components
For the system to function reliably, the site must adhere to routines for checking and maintenance. Tunnelling machinery and other equipment must not be placed so that it may block the signal between the tags and the monitoring stations. The sensors that record the movements must be cleaned weekly.

5.3 Use and administration of the software
It is easy to learn how to use the administrative software. It is important that several can operate the program, so that at all time personnel are available at site who can change and hand out tags. The administrative PC must be placed in the site office where people are present, so that unauthorised entries and malfunction messages are discovered and acted upon.

5.4 Overview of the site zones
The tunnel system to be monitored will be divided in security zones using colour codes. Boards that present easily understandable overview of the system and the monitored zones shall be displayed at the entrances and also be available on the computers . (The colour code for the zone division must coincide with the colour code on the PC display). A board should also be displayed in the office together with the emergency plan. Signs must be placed to inform and remind visitors about the access monitoring system.

5.5 Visitors' protocol
A visitors' protocol must still be kept. A visitor will get a tag that is recorded in the protocol with name, company and date.

5.6 Communication
The communication between the monitoring stations and the administrative computer at the site office may be wireless or by cable or as a combination.
Provided data communications systems are available at the site, these should be utilised.

5.7 Observations from the tests in the Bragernes tunnel
These are summarised in the table below:

Negative	Positive
- The system did not function as expected during the test period. - The enthusiasm of the users reduced gradually due to the instability of the system during the initial test period.	- The tags were correctly recorded by passing of the monitoring stations. - After several months of problems, new software solved the solved the instability problems. - Later tests have demonstrated that the new software is stable and that the system functions well.

6 OTHER APPLICATIONS
As the system basically identifies the presence of electronic cards (chips) within pre-defined control zones, it may be developed and adapted for:
- general access monitoring for other types of construction, industrial, or office workplaces;
- monitoring of transport and location of dangerous goods;
- managing quantities of deposited material

7 PRIVACY PROTECTION IN NORWAY
The use of Monitoring access systems are regulated by act and regulations. The Data Inspectorate, an independent administrative body, supervises. Concession is required for registers that contains sensitive information, other registers must be reported only. Registers required by the Work Environment Act which do not contain sensitive information are exempt from reporting.

The administrative computer will contain information about the tag, the name and company of the tag wearer. The system does not log the movements of the individuals; it can only show where the personnel (tags) are at any time, not previous or future locations. Only error messages are logged. It is not possible to record how many times an employee has passed in or out, or time for arrival at the work place. Hence information needed by the system is not sensitive. According to the regulations regarding personal privacy, an agreement is signed between the administrator of the system; usually the main contractor, any subcontractors, and all the individual users, including the tunnel owner, his staff and his advisers.

8 OTHER SYSTEMS

Today other systems have become available, partly utilising similar technology.

Some manufacturers have made available technology that have been used in other industries with promising results, and which may be acceptable for the tunnelling and mining industry. The market for access monitoring in tunnelling and mining is limited and the general interest from manufacturers is modest.

9 FURTHER DEVELOPMENT

The described development of electronic access monitoring for tunnelling and mining has been promoted by contractors and suppliers. Requirements from large tunnel owners, with a view to their overall responsibility for safety, for improved tagging systems would accelerate the development.

10 CONCLUSION

Based on the experiences achieved, the electronic access monitoring system is a useful tool to keep an overview of the personnel on tunnelling sites. More information is needed as well as the further development of thorough and practical routines. An introduction into the respective parties' HSE manuals is necessary.

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12 RECENT STUDIES OF HEALTH EFFECTS IN TUNNEL CONSTRUCTION WORK IN NORWAY.

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ABSTRACT

Apart from hard physical labour, tunnel construction workers are exposed to such agents as mineral dust with varying degrees of alpha-quartz, diesel engine exhaust (gases and particulate matter), nitrous oxides, chemical products (synthetic resins), radon and oil mist. These exposures may place them at an increased risk for lung disorders. Studies have shown changes in lung function and an increased frequency of respiratory diseases among tunnel workers.

Tunnel construction workers are further exposed to noise, vibration and poor lighting etc. Work related illnesses do not occur by chance. They do occur as a result of years of exposure to these agents and the actual working environment. Similar results are seen in different industries with similar exposures.

The general tendency in Norwegian construction work and tunnelling during the last 10-15 years is that workplaces do not seem to be getting much healthier (Myran, Furuseth, 1998).

1 EXPERIENCE OF THE WORKING ENVIRONMENT EXPOSURES AND EXPOSURE LEVELS

In tunnel construction work the number of contractors are relatively few. Some of these have been continually engaged in tunnelling for a period of more than 40 years. To minimise the size of the tunnel crews the workers do many different job tasks on the projects.

Because of the demand for reducing construction times for tunnel projects, increased mechanisation and productivity, the amount of air pollutants produced per time unit is increasing (Myran, 1974-2003). Exposure levels are periodically high compared to the Norwegian Occupational Exposure Limits, OEL, (Ulvestad et al, 2000).

In this study a total of 15% of the total dust measurements, 5% of the respirable dust and 21% of the alpha-quartz exceeded the Norwegian OEL's of 10 mg/m^3, 5 mg/m^3 and 0.1 mg/m^3 respectively.

In the above mentioned study, job groups with highest geometric mean total dust exposure were shotcreting operators, tunnel boring machine workers and shaft drivers (6.8-6.2-6.1 mg/m^3 respectively). The lowest exposed groups to total dust were outdoor concrete workers, electricians and support workers (1.0-1.4-1.9 mg/m^3).

Personal exposures to dust and gases were measured among 189 underground construction workers who were divided into seven occupational groups: drill and blast crew, shaft drilling crew, tunnel boring machine crew, shotcreting operators, support workers, concrete wor-

kers and electricians.
Shaft drivers had the highest exposure to oil mists (GM = 1.4 mg/m^3), that was generated mainly from pneumatic drilling. For other groups, exposure to oil mist from diesel exhaust and spraying of oil onto concrete forms resulted in exposures of 0.1 – 0.5 mg/m^3. Exposure to nitrogen dioxide was similar across all groups (GM = 0.4-0.9 ppm), except for shaft drivers and tunnel boring machine workers, who had lower exposures. High short term exposures (>10 ppm), however, occurred when workers were passing through the cloud of blasting fumes.

These results are based on measurements at 16 different tunnel construction sites between 1996 and 1999. With reference to the working environment generally, the chemical/physical factors such as dust, gas, noise, vibrations etc. are very similar in the construction and mining industries.

SINTEF has for nearly 30 years carried out testing and documentation of dust and other air pollutants associated with mining. This includes a series of investigations into dust containing quartz and other types of mineral dust associated with mining, open-pit mining, mineral quarrying, gravel, slate and other stone industry, tunnel and power station work places, along with other types of mining work. These investigations show that excesses of OEL occur more frequently within the construction industry and stone processing than in the mining industry. This is especially linked to differences in the quartz content characteristic to the type of mining and related dust, but also to the fact that the work intensity in construction operations can be rather more intense than for example in mining (Myran, 1974-2003).

2 WORK RELATED ILLNESSES (WRI)

During the years 1997-2002 a number of approximately 3,500 work related illnesses were reported yearly to The Directorate of Labour Inspection (DLI). Reduced hearing because of noise is the work related illness most often reported. Reduced hearing accounted for 47% to 54% of the reported cases of work related illnesses in this time period. Diseases of the lungs and respiratory tract accounted for 13% to 19% of the reported cases of work related illnesses in the same time period.

Construction work and tunnelling are the trades that top these statistics with 15%, 16% and 18% of the reported cases in the years 2000, 2001 and 2002.

Some years ago an investigation was carried out (Alteren, 1995) of the grouping of work related illnesses reported to the DLI from the mining industry in the period 1989-1993. This investigation showed that as much as 34% of reported work related illnesses were injuries to the nervous system, i.e. primarily injuries to hearing. Injuries or diseases of the respiratory system accounted for 28%. Such diseases included silicosis, asbestosis and other respiratory disorders caused by dust and gases.

The reported incidents were also classified according to which work environment factors had caused the work related illness. This showed that non-organic dust, noise and vibrations had caused most work illnesses. Repetitious monotonous and stressful work had brought about 12% of illnesses.

3 EXPOSURE AND HEALTH EFFECTS

In a study by Ulvestad et al. (2000) tunnel workers were compared to outdoor construction workers and were found to have a significantly higher exposure to total dust, respirable dust, alpha-quartz, oil mist, nitrogen dioxide and carbon monoxide. Exposure to dust in the tunnels was periodically high compared to the Norwegian occupational exposure limits. Both yearly losses of FEV1 related to exposure and prevalence of chronic obstructive pulmonary disease (COPD), were higher among the tunnel workers than in the reference group.
The tunnel workers were further divided into groups. Several of these subgroups (grouting workers and shotcrete operators) had an increased risk of asthma. Other groups (shaft drivers and tunnel boring machine worker) had substantial exposure to alpha-quartz. The study concluded that exposure to dust and gases in underground construction work enhances the risk for chronic obstructive pulmonary disease.

Tunnel workers using ammonium nitrate fuel oil (ANFO) as the explosive show a temporary reduction in lung function, whereas those using size-sensitised emulsion (SSE) do not. The most likely explanation for the observed changes is peak exposures to nitrogen dioxide (Effects of blasting fumes on exposure and short-term lung function changes in tunnel construction workers, Bakke et al., 2001).

Respiratory effects of exposure to several of the measured agents have also been reported in other studies; bronchi-alveolar inflammation because of short-term (1 hour) exposure to diesel exhaust, occupational asthma due to oil mists (study of machine shop workers), and alpha-quartz exposure has been shown to be an independent predictor for spirometric airflow limitation.

Different studies show, or indicate, a connection between exposures and health effects. However, it is still concluded that it is not clear which exposures, or combination of exposures, cause the observed effects.

4 OTHER HEALTH EFFECTS DUE TO EXPOSURE IN TUNNEL CONSTRUCTION WORK

4.1 Acrylamide

During grouting operations workers may be exposed to acrylamide and N-methylol-acrylamide tunnel work. Studies on health effects from exposure of acrylamide and N-methylol-acrylamide have shown slight, but mainly reversible effects on the peripheral nervous system (Kjuus et al., 2002).

4.2 Noise

Within drilling and blasting, noise is probably the individual factor, which causes the most injuries at work. In the mines hardly any 50 to 60-year old worker with a long working background within drilling and blasting and other underground work had normal hearing. The large majority is more or less hearing-impaired. This applies both to tunnelling and to mining.

5 OTHER RESULTS WITH RELEVANCE TO TUNNEL CONSTRUCTION WORK AND HEALTH EFFECTS

During the time period from 1989 to 2003 more than 1.000 workers (mineworkers, foundry workers and electrical fitters) have been investigated with reference to exposure, reduced lung function, lung diseases and cardiovascular diseases.

SINTEF has for nearly 30 years carried out testing and documentation of dust and other air pollutants associated with mining. The objectives here have been both a documentation of the exposure-level to dust for individual workers, along with deciding the background level of dust in different work undertakings and within different work areas.

The content of alpha-quartz in the presently active mines, both open pit and underground, varies between 0 % and 50 %. Dust investigations carried out indicate that the danger of silicosis must still be regarded as real in a number of mining situations, in mineral quarrying and in tunnelling.

Medical supervision of the employees exposed to dust varies considerably, from hardly anything to systematic purposeful investigations. There is great variation in the frequency of investigations, what is investigated and how the investigation is carried out. The collective picture for the industry is as a result very mixed. It is particularly difficult to recognise occupational lung diseases (Wolkonsky,1982). Mowe (1995) has documented a severe underreporting of pleural mesotheliomas in Norway. The statistical exercises dealing with the development of silicosis in Norway are incomplete. Numbers are uncertain, which means that incidence numbers must be interpreted with caution. In all there are reported to the DLI about 4,000 cases of silicosis in Norway. Of these, about 40% come from the mining industry and about 8-10% from tunnelling and the construction industry. Because of great variation in the follow-up of these workers there are grounds for asserting that the early stages of silicosis will be overlooked (Furuseth et al, 1991).

Among the workers examined we find an obstructive tendency in the spirometric results. The same tendencies, although in varying degrees, are seen among workers in the different mineral quarries, in the mines, among foundry workers and among the electrical fitters.

Workers with reduced lung function seem to have a higher exposure to mineral dust compared to healthy workers. The occurrence of lung disease and reduced lung function will depend on which criteria are adopted. There is however ground to claim that among those investigated can be found a large number with reduced lung function. In one of the mines a number of tests were carried out for the evaluation of possible reversibility of reduced lung function. The test together with clinical examinations revealed a lot of miners with moderate obstructive bronchitis, but little reversibility judged by the spirometric results.

Tobacco smoking has been identified as an important risk factor in causing reduction in lung function (Kibelstis, 1973) and chronic airways disease. It is also now growing evidence that airway obstruction (COPD) are caused by exposures other than tobacco smoke, and that occupational exposures, particularly to dusts, are amongst such causes (Burge, 1994). The obstructive tendency in the spirometric results is found among workers exposed to inert dust and workers exposed to dust with alpha quartz.

6 DISCUSSION AND CONCLUSIONS

Whether tunnel construction workers have an increased risk of work-related chronic obstructive pulmonary disease is debated (Ulvestad et al., 2000). Results from similar type of industry (mining and other industries with high exposures to mineral dust and gases, such as foundry workers) show a high percentage of workers with increased reduction in lung function (FEV1), reduced lung function and lung diseases.

Exposure assessments are associated with a high degree of uncertainty. Working in the construction industry per se is not a useful indicator of exposure because construction work incorporates many different types of tasks that have a variety of exposures. Work site allocation is also not useful because construction workers are typically employed at a large number of sites with differing working conditions throughout their career.

However, investigations show that excesses of OEL occur more frequently within the construction industry and stone processing than in the mining industry. Respiratory effects of exposure to several of the measured agents (mineral dust, gases and particulate matter, NO2 etc.) have been reported, both reversible and irreversible.

Tunnel construction workers as well as miners are liable to contract parts of the above mentioned exposures, and in varying degrees. Results from similar industries (miners, electrical fitters and foundry workers) based on follow up studies over many years, also show that workers with reduced lung function and lung diseases seem to have a higher exposure to mineral dust compared to healthy workers.

The documented high levels of the different exposures seem to be sufficient to cause the observed changes in lung function and lung diseases seen among tunnel construction workers and workers in similar trades.

Experience from the industry indicates that results of health surveys and occupational examinations are often neither put together nor compared, see Figure 1.

Fig. 1: Co-ordination of studies?

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13 HEALTH ASPECTS OF SPRAYED CONCRETE

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Summary

The Norwegian Public Roads Administration initiated in 1998 a research project highlighting health and safety during shotcreting. The application of sprayed concrete is one of the most risky processes with respect to health in underground works. One of the main tasks of the project was to assess the work environment and also to investigate different actions for improvement.

The tests included both alkali-free accelerator and silicate based accelerator (water-glass). The results indicated a large spread in the exposure levels for total and respirable dust for the same type of accelerators. Compared to the Norwegian administrative norms, the exposure levels are high. With use of a closed cabin on the spraying rig, the operator's exposure to respirable dust is reduced by 44 %.For total dust the exposure is reduced by 74 %. One advantage with a closed operator's cabin is that the operator's chemical exposure is reduced by way of reduced dust exposure.

It is recommended that the operator uses a respiratory protective device when working outside the cabin.

1 INTRODUCTION

The health and safety project Sprayed Concrete was initiated by the Norwegian Public Roads Administration in 1998 as a part of a continuous research and development programme for increased safety and improvements of the work environment in connection with tunnelling. Concrete spraying is one of the most hazardous work operations underground in terms of health. In addition to being exposed to concrete dust, sprayed concrete operators are also exposed to diesel exhaust. Studies performed by the occupational health service at contractor Selmer Skanska (then Selmer ASA) showed that this group of operators has an increased risk of developing asthma in comparison with the tunnel face workers.

Based on these health screenings, and previous exposure measurements carried out at the National Institute of Occupational Health (STAMI), the objective was to assess the effect of various measures to improve the work environment. Additionally, there was a wish to examine whether the use of an alkali-free accelerator reduces the dust load in air in comparison with a silicate based accelerator (water-glass). The effect of a closed operator's cabin on the spraying rig was also investigated. The use of an alkali-free accelerator may contribute to increased safety for work at tunnel face. Therefore, the project also included a full-scale testing with regard to early strength development and durability of the sprayed concrete. Results from this supplementary program are not presented in this article.

1.1 Health hazards in connection with sprayed concrete

Concrete spraying is one of the most hazardous work operations underground in terms of health. A follow-up study of 17 sprayed concrete operators that was carried out by the occupational health service at Skanska Norge over a period of 8 years showed that these operators as a group has increased risk of developing asthma in comparison to tunnel face workers. The annual drop in lung function (FEV1) was twice as high as expected. Concrete spraying is an operation where large amounts of dust are developed. This is because the concrete is split up as it leaves the nozzle and is sprayed onto the rock surface under high pressure. In addition the operators are often exposed to diesel exhaust. Several studies have indicated that diesel exhaust may lead to the development of asthma. Furthermore, the operators are exposed to oil mist when the rig is sprayed for cleaning purposes.

1.2 The aim of the project

The project aimed at surveying exposure of the sprayed concrete operators with regard to aerosols and gases, and to compare alkali-free and silicate based accelerators.

The results from the survey will be used in connection with the assessment of the operators' exposure in relation to the administrative norms. They may also form the basis of proposals for measures to improve the work environment.

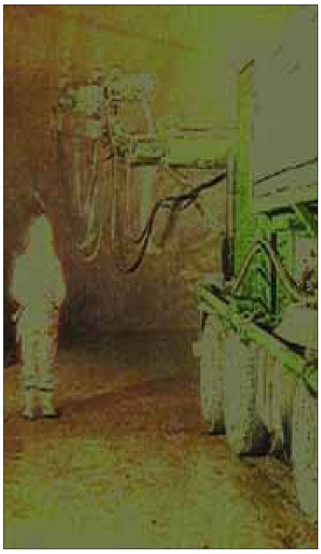

Fig. 1: Controlling the spraying rig from the tunnel floor

1.3 Organisation

The work was coordinated by the Norwegian Public Roads Administration. The joint venture has consisted of representatives from STAMI, the contractors Veidekke and Selmer Skanska, as well as the Norwegian Public Roads Administration.

STAMI has been in charge of carrying out the work environment measurements, as well as the analyses of samples. Veidekke ASA has been in charge of measurements in connection with early strength and durability. The concrete spraying has been carried out by subcontractors.

1.4 Implementation

The first phase of the project was carried out in Elskauåsen tunnel on the Oslofjord Connection Project. The spraying was carried out by contractor PEAB using a Meyco spraying rig. The study of the effect of a closed cabin on the spraying rig was carried out in Fossna tunnel in Hordaland county. The tunnel was excavated by the Public Roads Administration's construction division. The spraying contractor was Entreprenørservise AS. A spraying rig with a closed cabin from AMV was used.

Both spraying rigs were made available for the test program by Mesta (previously the construction division of the Norwegian Public Roads Administration). The concrete mix had alkali-free accelerators. Additives from the suppliers Scancem Chemicals, Rescon AS, Sika Norway and Master Builders Technology respectively were tested.

2 CRITERIA FOR ASSESSMENT REGARDING EXPOSURE

In order to assess whether conditions that are hazardous to one's health exist in connection with exposure, the Administrative Norms for Pollution in the Working Atmosphere from the Norwegian Labour Inspection Authority is used. These criteria are as follows:

Measuring result < 1/4 of the norm:
- No requirement for measurements be followed up.
- Acceptable.

Measuring result > 1/4 of the norm, but not above the norm:
- Discernible problems, measures are being assessed.
- Regular control measurements are ordered.

Measuring result > administrative norm:
- Critical problems, immediate measures required.
- Plan of action and time schedule ordered.
- Control measurements required after measures have been implemented.

Administrative norms in Norway:

Nitrogen dioxide (NO_2):	3.6 mg/m^3, 2 ppm (max. value)
Carbon monoxide (CO):	29 mg/m^3, 25 ppm
Oil mist:	1 mg/m^3
Oil vapour:	50 mg/m^3
Bothersome dust, total dust:	10 mg/m^3
Bothersome dust, respirable dust:	5 mg/m^3
α-quartz, respirable dust:	0.1 mg/m^3.

Except in the case of nitrogen dioxide, the norms indicate the highest acceptable average concentration during an 8-hour shift. This means that the norm may be exceeded for short periods of time if the concentration for the rest of the shift is kept so low that the average concentration for the entire 8-hour period is below the norm. The norm for nitrogen dioxide is a maximum concentration which must *not be exceeded.*

3 RESULTS OF WORK ENVIRONMENT MEASUREMENTS

The survey included 10 measuring days for each supplier (with the exception of Scancem). A total of 5 people have carried sampling equipment. Personal sampling equipment with the air intake close to the breathing zone was used. Figure 2 shows how the sampling equipment was carried. All analyses were carried out by STAMI.
For total dust, the results indicate a large spread in the exposure levels for the same type of accelerators. Compared to the administrative norm, which is 10 mg/m^3 for total dust, the results are high. See Figure 3. The same applies to respirable dust. The results are high compared to the norm of 5 mg/m^3. See Figure 4.

An analysis of the quartz content shows concentrations in the area 0.003-0.04 mg/m^3. The results are lower than 1/3 of the administrative norm; thus, they are acceptable.

The tests for oil mist and oil vapour indicate concentrations of oil mist in the area 0.03-0.87 mg/m^3, the average concentration being 0.53 ± 0.28 mg/m^3. This is more than 1/3 of the administrative norm, i.e. discernible problems. The administrative norm for oil mist is 1.0 mg/m3. The results show that the operators may be significantly exposed to oil mist when the rig is sprayed with formwork oil. When the formwork oil is sprayed on, it will be necessary to use a respiratory protective device. The tests indicate concentrations of oil vapour in the range of 1.80-10.10 mg/m^3. This is acceptable in comparison to the administrative norm for oil vapour of 50 mg/m^3.

Some random samples of carbon monoxide (CO) and nitrogen dioxide (NO_2) were also taken. The results indicate very low concentrations of both gases. This is because the spraying rig was run by electricity, and there was good ventilation to the work face. Previous measurements have shown that if the rig is run by diesel, the concentration of NO_2 may exceed the administrative norm.

Conclusion: Respiratory protective device is required.

4 WORK ENVIRONMENT IN CONNECTION WITH CONCRETE SPRAYING – CLOSED OPERATOR'S CABIN

Based on results of exposure in connection with concrete spraying, there was a wish to also look at the effect of the use of a closed operator's cabin in the experiment. Additionally, various combinations of filters on the cabin's air intake were tested.
Three tests were carried out for different filter combinations on the spraying rig cabin:

- coarse filter + bag filter EU7 + coarse filter + electrostatic filter + coarse filter
- coarse filter + bag filter EU7
- coarse filter + electrostatic filter + coarse filter.

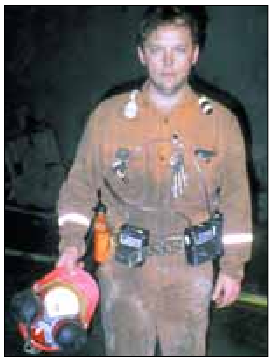

Fig. 2: Placement of sampling equipment on operator

Measurements have been undertaken inside and outside the cabin, as well as on the operator. Each series of tests consisted of measurements of both respirable dust ("fine" dust) and total dust ("coarse" dust).

The same operator was used for the entire experiment. Out of a total of 16 measurements, 8 measurements were carried out using an alkali-free accelerator (Rescon), and 8 measurements using a silicate based accelerator. The tests were carried out 150 to 315m from the tunnel portal.

The results show that the operator's exposure varies with each spraying round. This is a result of different work patterns, e.g. how often he enters and leaves the cabin throughout the spraying period. Based on the measurements carried out, no conclusions can be made with regard to what are the best filter combinations. The sampling time was too short. Also, the number of measurements carried out was not sufficient to establish any difference between the various filter combinations.

The results show that with a closed cabin, the operator's exposure to respirable dust is reduced by 44 %. For total dust the exposure is reduced by 74 %.

5 RECOMMENDATIONS

One great advantage with a closed operator's cabin is that the operator's chemical exposure is reduced by way of reduced dust exposure. However, physical exposure

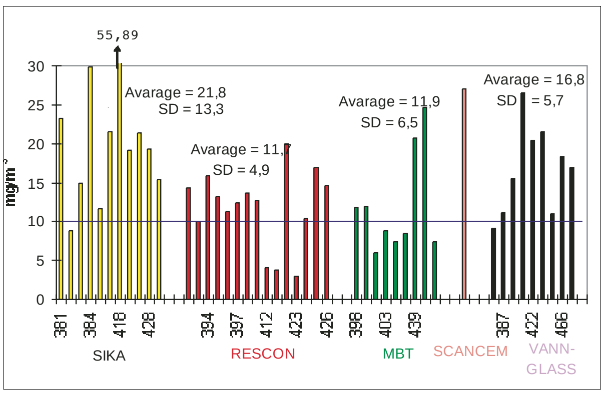

Fig. 3: Results total dust.

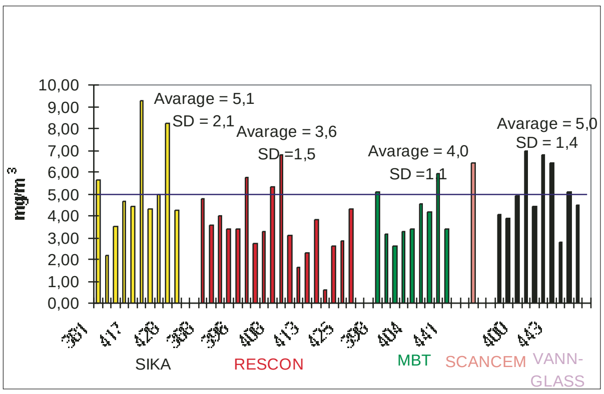

Fig. 4: Results respirable dust

in the form of noise and draught will also be reduced considerably, and this will increase the well-being in the work situation.

Arguments against the use of this equipment have been that, since the operator often has to leave the cabin while spraying is taking place, the effect of sitting inside the cabin will be reduced considerably. Furthermore, the introduction of equipment which protects the spraying operator does not reduce the exposure for others staying in the work zone. Special thought is here given to the concrete supplier. In this connection, one needs to consider the fact that during spraying, the person who is closest to the source, i.e. the operator, will experience the highest degree of exposure. In most cases, the operator will also stay in the work zone throughout the entire shift, which the concrete supplier will not.

The results show that the operator's exposure is reduced considerably when the operator's cabin is closed, despite the fact that there may be a great deal of movement out of and into the cabin.

It is recommended that the operator uses a respiratory protective device when working outside the cabin.

6 FURTHER WORK – CONTRIBUTING TO THE IMPROVEMENT OF THE WORK ENVIRONMENT FOR SPRAYING OPERATORS

The joint venture concluded that further work is required in the following areas:

- Reduction of diesel exhaust; investigate different filters for particles/soot
- Cleaning of the tunnel air; electrostatic filters
- Assessment of the effect of various filters on the air intake into the operator's cabin

Since the described project concluded in 1999, a test has been performed about the use of an electric driven concrete transmixer instead of the normal diesel powered. This showed an improvement of the work environment. The concentration of oil mist with diesel-powered transmixer was significantly higher instead of electric driven transmixer. In the subsequent "Diesel Underground" project (see paper no. 9 in this publication), cleaning of diesel exhaust by particle filtration was further investigated.

Fig. 5: Entreprenørservice's spraying rig, «Bjørnen», with a closed cabin.

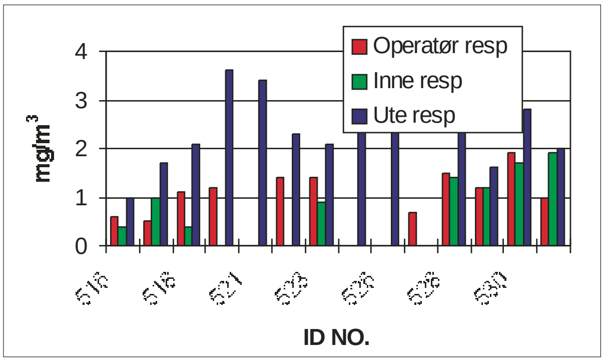

Fig. 6: Concentration of respirable dust on operator inside and outside the cabin. (Green is outside cabin, blue is inside)

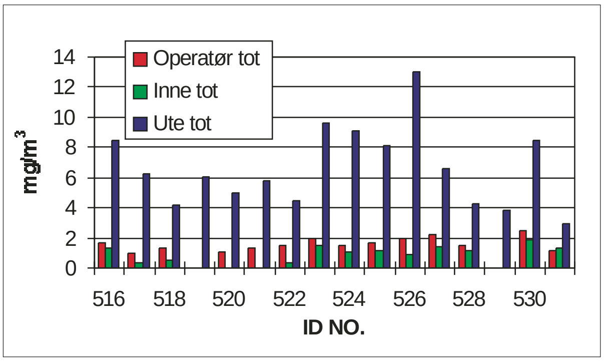

Fig. 7: Concentration of total dust on operator inside and outside the cabin. (green is outside cabin, blue is inside)

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