

# **Intern rapport nr. 2168**

**Lining designs for Norwegian  
road tunnels  
Proc. World Tunnelling  
Congress `99  
Challenges for the 21st  
Century**

**Juli 2000**

**Vegteknisk avdeling**

## Lining designs for Norwegian road tunnels Challenges for the 21st Century Proc. World Tunnelling Congress, Oslo `99

### Sammendrag

**ABSTRACT:** To overcome communication difficulties in the Norwegian landscape of mountains and fjords, 850 road tunnels have been built. Half of these tunnels have a traffic volume less than 1000 AADT, as they are primarily links to scattered settlements. Panels made of frost insulated, aluminium corrugated sheets and PE-foam linings have been in extensive use. Recently, shotcrete/PE foam linings, PVC-coated polyester fabric linings and prefabricated concrete elements of special designs have been introduced. Applying separate methods to accomplish the rock support and the water/frost protection is one of the basic principles of the NPRA road tunnel design. It has been found that this yields an optimum between performance and economy.

Emneord: *Road tunnels, linings, water sealing, frost protection, tunnel support.*

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## 1 REASONABLE TUNNELS NEEDED FOR ROAD DEVELOPMENT PROGRAMME

The development of road connections between the scattered settlements in the Norwegian fjord and mountain regions is to a large degree dependent on tunnels. From an annual output of 15 km excavated per year in the 1960's, tunnelling had increased to almost 50 km/year at the beginning of the 1990's.

Up to present, about 850 tunnels have been excavated, with a total length exceeding 600 km. In the last 15 years, undersea tunnels are even made an alternative to bridges for island connections or fjord crossings. At present, a number of 17 with a total length of 55 km are in operation, another 5 is under excavation (Figure 1).

A most remarkable feature is the proportion of low traffic road tunnels. About 50 % of the tunnels have a traffic volume less than 1000 AADT, and 20 % even less than 500. About 20 % have AADT above 5000, and in the urban areas a traffic volume up to 60 000.

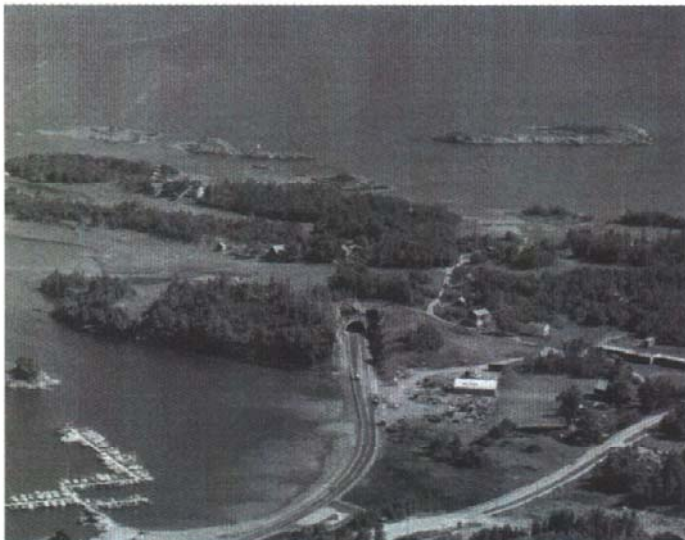


Figure 1: Subsea tunnels are introduced as an alternative to bridges.

## 2 PRINCIPLES OF NPRA ROAD TUNNEL DESIGN

If NPRA is to be able to continue its ambitious road tunnelling programme, optimizing is vital. One of the main ways to achieve this is to avoid using expensive cast in situ concrete linings for rock support and water protection. Efforts have been going on since the 60's to optimize lining alternatives. The principles arrived at may be summarized in 13 items:

1. Initially all phases from planning, construction, operation and maintenance should be considered for achieving an optimal design.
2. Careful geological studies is required for cost estimation, design and construction planning.
3. The tunnel should be located in the best possible ground.
4. Circular cross sections should be adopted or approached.

5. Standardized cross sections should be adopted.
6. A smallest possible number of support methods should be adopted.
7. Careful blasting procedures should be adopted to conserve the stability of the rock.
8. Rock support should exploit the inherent, self-supporting capacity of the rock.
9. Permanent rock support at lowest possible cost, normally rock bolting.
10. Heading support should not obstruct the installation of the permanent support.
11. Heading support methods to form a part of the permanent support should be selected.
12. Rock support and water/frost protection should be dealt with separately.
13. Water and frost protection is achieved by cost-efficient designs.

### 3 ROCK SUPPORT METHODS

A rock mass have an inherent selfsupporting potential that may be exploited by supplying it by means of cost efficient support methods. Rock bolting is a method which combine this goal with good performance and flexibility [ 1 ].

Rock bolting was introduced for rock support in the late 1950's, and has later on, in combination with rock straps and nets been made the general method for both preliminary and



Figure 2: Rock bolting is extensively used for support.

permanent rock support (Figure 2). In situ load tests and sampling made by core drilling of in situ rock bolts have been adopted for studies of the condition of the bolts. The studies prove that the condition of fully grouted rock bolts are satisfactory. Even 20 years old bolts anchored by polyester glue cartridges performed well, provided the bolts were coated by a satisfactory protection against corrosion.

Poor rock conditions have to be handled by special methods Shotcrete combined with rock bolting has its main advantage as a heading support in poor, highly fissured rock. Sections containing clayey rock are dealt with by the use of careful blasting, shortening the round length, pilot tunnelling, shotcreting, forepoling and eventually in situ concreting by means of steel shuttering.

However, the shotcreted sections have generally to be provided with protective panels against water leaks and, where necessary, frost damage. Where panels are installed in leaking and poor rock sections, the rock support is normally hidden for future inspection. Very careful mapping prior to shotcreting is therefore required to achieve a rock support of a satisfactory safety level

#### 4. WATER SEALING TECHNOLOGY

Support to a high degree based on rock bolting or shotcrete leaves the problems associated with water leaks, ice-up and frost action to be solved. Where it is not required to maintain or reestablish the ground water level, the development of special designs for water protection has proved to be of vital importance.

Installation of a water sealing of high quality is a good investment. This has been specially documented for a city road tunnel that was taken into operation with an in situ concreted lining only. The cost of the traffic regulations, maintenance and repair work caused by water leakages and frost only through 40 years far outweighed the costs of installing a high quality, double concrete lining with membrane isolation [ 2 ]. So-called watertight concrete also has been used in recent projects, with unsatisfactory results.

As a consequence, satisfactory sealing can only be achieved by the installation of special materials, called membranes. Membranes are materials with very low permeabilities, used in thin sheets as a water barrier for the protection of buildings. Besides resistance to water, the membranes have to be resistant to corrosives, frost, microorganisms, migration of softeners and penetration by roots.

Various materials are used for membranes. Asphalt has been in use for more than 5000 years, also metals like steel or copper, and the recent ones include plastic foils and bentonite-impregnated sheets, all of them still actual. The various membrane types is approved or specified for each type of lining. As important as the choice of membrane is the quality of the installation. Strict specifications have to be imposed to obtain the result aimed at [ 3 ].

#### 5 NPRA DESIGNS FOR WATER/FROST PROTECTION AND LINING FINISHES

Construction according to the principles of NPRA design has major consequences for the economy of tunnel projects. Only because of the austerity of this protective design has the

extensive road development over the past 30 years in Norway been possible. Experience to date shows that with good planning and careful implementation, it is possible to combine austerity with a high safety level [ 4 ]. In order to optimize water-protection methods suitable for ordinary Norwegian road tunnels, the NRRL has been involved with development work in this area since the 1960's [ 5 ].

A number of systems for protecting road tunnels against water and frost have been tested and implemented. Along with increasing traffic and stricter safety standards, the trend recently is directed to linings presenting better maintenance properties and contribute to a higher safety level. A number of facilities are being put up today with water and frost-proof linings which are a combination of two methods. Mostly used is the combination PE foam/shotcrete on the roof and concrete elements on the walls. The following provides an overview of the tested methods and methods still being developed.



Figure 3: Grouting for water sealing by means of chemicals and high pressure.

## 6 WATER-PROOFING BY GROUTING TESTED

Grouting technology was the first method studied because it was considered having the potential confining the water at a frostfree depth in the rock (Figure 3). Injection by chemical grouts (mostly chromate/lignin), executed after the tunnel was excavated was extensively tested in many sites throughout ten years of time (post-injection). The method was not found to have the quality necessary for permanent water-proofing of road tunnels, and it was therefore not included in further development programmes.

However, grouting in front of the tunnel face, before excavation (pre-injection) is applied to a high extent in undersea tunnel projects, or in areas vulnerable to lowering of the groundwater table. The results are dependent on the ground conditions and the resources applied. The method is, however, not an alternative to an icing protective lining, but good results have often been achieved as to the lowering of the total water inflow into the tunnel.

## 7 LIGHTWEIGHT STRUCTURES

A concept which involves deflecting water leakage all the way down to the trench was considered early on. The designs embarked upon included panels made of aluminium, steel, sandwich elements, PE-foam and PVC fabric. Lightweight linings cannot withstand rockfall, vehicle impacts or ice loads. The designs should therefore encompass full protection against rockfall and impacts and, where harmful frost quantities occur, full frost insulation.

The distribution of frost in the tunnels have been mapped in terms of frost indexes, and dimensioning of frost protection specified. Air pressure pulses generated by high-speed heavy traffic also impose a significant stress on the lightweight structures. This is an aspect that must be encountered in evaluating the different designs. Specifications now require designs dimensioned for air pressure loads of  $400 \text{ N/m}^2$ .

### 7.1 Metal sheet linings

The design consisting of corrugated aluminium sheets was extensively used in the 1970's and 1980's. Single sheet linings were used in low traffic road tunnels subjected to small amounts of frost, i.e. frost index up to  $3000 \text{ h}^\circ\text{C}$  (Figure 4).



Figure 4: Water and frost protective panel made by corrugated aluminium sheets.

Frost-insulated sheet-metal lining consists of two aluminium circular shieldings enclosing an insulating layer of mineral wool mats. The lining layer facing the road is self-bearing, but also stabilized by means of rigid pipe arches. The lining has a more flexible structure than the uninsulated type, so that traffic induced air pressure impacts are absorbed better.

New designs made by boards consisting of a single sheet of aluminium, mineral wool mat insulation with an overlay of high-quality plastic foil replacing the rockside aluminium sheet. They are installed by means of profiles anchored to the surrounding rock. Initial linings have been of varying quality and enforced stricter specifications [ 3 ].



### 7.2 Plastic sandwich linings (PUR/PETP)

The most commonly used sandwich lining was first installed in a tunnel in 1982, and shaped as half-arches fixed to a rail anchored in the rock, running along the centre of the crown. It was developed to bring about more rational production, simplify erection and replacement, and make installation faster (Figure 5).

It consists of 50 mm polyurethane (PUR) foam enclosed in hard-wearing, diffusion-proof glass fibre reinforced polyester. This thickness is adequate for frost indexes of up to 20 000 h°C glass-fibre-reinforced polyester (PETP) with a thickness of about 1 mm. If the lining is damaged by vehicle impacts, at least one half arch must be replaced. To encounter this drawback, linings made from sandwich boards have been designed.



Figure 5: Installing the sandwich lining is efficient.

After having made extensive fullscale fire tests in abandoned road tunnels, however, it was found that the designs is no longer could be approved because of their combustibility [ 6 ]. However, the same type sandwich lining has been installed in Middle-European road tunnels later on [ 7 ]. Noncombustible sandwich linings was expected to be soon on hand, but further developments are delayed.

### 7.3 Water and frost protection with PE foam sheets

The PE foam lining consists of mats of extruded polyethylene foam glued together to sheets of appropriate size. The sheets are suspended by means of bolts and arch-shaped steel straps

mounted along the tunnel cross section and joined together in the tunnel length direction by means of overlaps.

Experiments involving insulating road tunnels against frost with sheets of PE foam were started in road tunnels about 1980. Initially developed for sealing point leaks and local water curtains, they were soon taken into use for lining the entire tunnel profile. The surface of the lining follows the rock contour, and its appearance reflects this. Because of their flexibility and ease of erection, their use were increasing rapidly.

PE foam is highly combustible, and full-scale tests undertaken show that the linings have to be fire protected by some types of fireproof barriers [ 3 ], [ 6 ]. Accordingly, fire protection of PE-foam linings were ordered from 1994 on. The ordinary lining introduced consisted of steel reinforced shotcrete applied on the PE foam surface in a layer 70 mm thick.

For the Ekeberg tunnel, a new concept for PE foam/ shotcrete lining, having the potential of producing absolute water-proof linings, was developed. The difference compared with earlier methods, is that the PE foam sheets are installed without overlaps and penetrating bolts into water-proofed steel arches, bolted to the rock tunnel profile.

#### 7.4 Tunnel fabric

The tunnel fabric lining is marketed under the name of WG tunnel sealing. The fabric satisfy stringent requirements regarding coverings for lorries as well as storage halls. Stores made of fabric are finding a growing number of applications and fabric has also started to be used for water-proofing caverns and underground galleries.



Figure 6: Lining made by PVC/polyester tunnel fabric.

The tunnel fabric consists of high quality PVC-coated 9x9 polyester fabric with a weight of 700 g/m<sup>2</sup> (Protan quality 55401). It is erected by clamping it between backing pipes, bolted to the tunnel periphery and pipe bands. The fabric is clamped against the backing pipes by means of erect pipe straps. All bolts are passed through at mat junctures.

The lining is resistant to wear due to dripping water, chemicals and oil resulting from normal use of the tunnel. However, it has to be given selective additives to prevent various microbial attacks. The erection time is short and the tunnel fabric is simple to repair. It has been classified as fire-proof because its fire load and fire spreading ability is very low. The fabric can stand moderate rockfalls and ice loads has up to present not produced any problems.

## 8 CONCRETE ELEMENT LININGS

In order to meet requirements to more cost-effective than the designs available on the market, concrete elements linings have been developed. These developments relate to frost insulation, easier handling, transportation, erection and reduced space requirements. Designs introduced in 1989 have been undergoing continuous development as new experience is acquired.

One important principle includes the installation and stabilization of the elements by means of through-going bolts. The elements are erected rapidly and simply by means of special equipment. The wall elements are erected first and anchored to the rock wall by means of rockbolts. In order to reduce breakage, increase precision and production, rational erection machines with hydraulically controlled vacuum plates have been developed.

The membrane foil rolls are placed on the lining, welded and rolled stepwise out as the elements are erected. The bolt holes are moisture-proofed by means of a double set of metal disks, rubber washers and nuts clamping the whole in place. The concrete element method is complicated for tunnels that have frequent changes in the tunnel cross section.

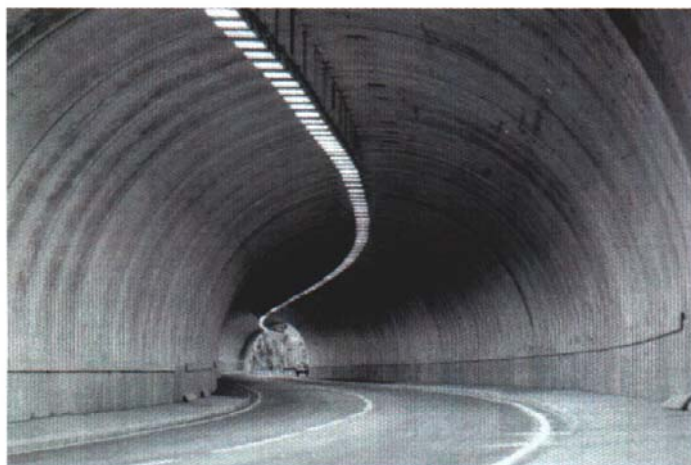


Figure 7: Light-weight concrete lining improved handling and frost insulation, but breakage was increased

The frost insulated elements are composed of extruded polystyrene ( XPS) foam mats sandwiched between concrete layers. The first lining used was in the Nordby tunnel south of Oslo, where a total of 7.5 km was installed. The lining is tripartite, with roof elements 2.5 m and wall elements 5 m wide.

## 9 CONCLUSIONS

Due to the escalating rate of road-tunnel construction in recent years, an increasing number of designs have been developed. New guidelines for fundamental requirements and design prepared by the Norwegian Public Roads Administration (NPRA) are now under revision. New materials and technologies produce continuously possibilities for new and improved lining designs. Another factor now important to study are how to make designs to promote traffic safety, driving comfort and aesthetic.

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