Better performing inner liners

Heidi Berg
Vianova Systems as, Norway
Authors

- Harald Buvik (N)
- Bernt Freiholtz (S)
- Olav Svangsttu (N)
- Kjell Windelhéd (S)
- Finn Raun Gottfredson (DK)
- Bjarne Liljestrand (F)
- Olli Niskanen (F)
- Armgarð Steinhólm (Fa)
- Hreinn Haraldsson (I)
- Heidi Berg (N)
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Report from a work-group of the 32 committee
- Overview of different inner lining solutions
- Experiences
- To what extent are they used?
- New materials and methods
- Lifetime and durability
- Fire safety
**Base of experience**

**Norway**
- More than 900 road tunnels in Norway ( >800km in total)
- Build approximately 20-30 km of new tunnels each year
- 23 sub-sea tunnels
- Low traffic tunnels are the most common. High traffic tunnels only in the big cities.

**Sweden**
- 23 road tunnels, 15 with inner lining (>18km in total)
- Have experience with 7 different inner lining solution

**Finland**
- Only few tunnels in Finland is owned by the road department (~2,3km)
- 17km of road tunnels are under construction
- 1 sub-sea tunnel
**Base of experience**

**Iceland**
- 7 road tunnels (>20km in total)
- 1 sub-sea tunnel
- Mainly low traffic tunnels

**Denmark**
- 4 road tunnels (>20km in total)
- 1 sub-sea tunnel (Øresund, 4km)

**The Faroe islands**
- 18 road tunnels (>41.5km in total)
- 2 sub-sea tunnels
- Mainly low traffic tunnels
Functional and technical requirements

A comparison of the requirements to inner lining in tunnels, show a highly complex picture. The constructions complexity, altered in both functional and technical requirements, is unfortunately too often underestimated.

Both protection and sustainability towards:
- Water
- Frost
- Fire
- Pollution
- High pressure cleaning
- Load

Visual requirements
- Clean / Bright
- Reflection of light
- Driving experience for the user
- Optical alignment
**Functional and technical requirements**

In addition the lining must be:
- Efficient to mount (industrialized process)
- Easy to replace just parts of it
- Easy access for inspection
Technical solutions _ inner lining

The experience from the Nordic countries is that pre-fab concrete element has the best durability in high-traffic tunnels and is also the most used.

In low-traffic tunnels other solutions like PE-foam or different membranes in combination with sprayed concrete is the most used solution.
Technical solutions _ inner lining

• PE-foam combined with mesh reinforcement and sprayed concrete
  – Experience: Used a lot in Norway and Iceland. Good results on water and frost protection. Test results for fire protection, show acceptable values (min 8cm concrete). Good durability. Low cost. Flexibility in geometry.

Pre-fabricated concrete and PE foam

Södra Länken, Stockholm. Concrete roof, bare walls. Foto: Mikael Ullén
Technical solutions _ inner lining

- Pre-fabricated concrete elements with isolation
  - Experience: Used a lot in Sweden and Norway on high traffic tunnels. Good results on water and frost protection. Good results on durability and cleaning. Expensive. Not very flexible regards to geometry.

- Metal sandwich panels
  - Experience: Most used in the Faroe islands and Norway. Some in Denmark. Good results on water and frost protection. Not to good on durability. Not very flexible regards to geometry.
**Technical solutions_ inner lining**

- Spayed membrane combined with mesh reinforcement and sprayed concrete
  - Experience: Used some in Finland and Sweden. Low cost. Hard to get a sustainable solution.
- Mounted membrane combined with mesh reinforcement and sprayed concrete
  - Experience: Used some in Norway and Sweden. Good results on water and frost protection (when 8cm concrete). Test results for fire protection, show acceptable values. Hard to keep clean. Flexibility in geometry.
Example from Södra Länken, Stockholm Sweden.

Concrete roof, sprayed concrete walls:
Experience: Hard to keep white roof clean. Expensive to mount the heavy concrete roof elements. They have also experienced some problems with water and building up of ice.

Foto: Mikael Ullén
Example Kopparberget, Finland

Sprayed Polyurethane on rock surface.

Mesh reinforcement in the roof, and sprayed concrete with polypropylene fiber in roof and walls.

Experience from this tunnel:
- The polyurethane forms “pockets” of water
- Cracks gives leakages
- Doesn’t protect against frost, because of too much water “stored” in the construction
- Problem with corrosion
Fire safety requirements for inner linings

The big tunnel fires in Europe contributed to put an extra focus on fire safety in tunnels. To find and test non-flammable and fire resistant materials has been a prioritized area for all Nordic countries, and the result has been used in this report.

The construction should not
– contribute to a fire
– spread a fire
– continue after the source is neutralized
– develop smoke or toxic gasses

Dimensioning time/temperature curves
Cost-benefit evaluation

Traditionally it is only the investment cost that is taken under consideration, when an inner lining solution is selected, but this is only a part of the total cost in the lifetime of the construction. The solution that is selected, will influence on the cost for operation and maintenance during the whole lifetime of the construction.

LCC

- Investment cost
- Maintenance cost
- Operation costs
- Cost for traffic and accidents

\[ N = \sum_i \frac{a_i}{(1 + r)^n} \]
Example

LCC cost for

Metal sandwich panels
• 600kr/m2
• 12-15 years lifetime

Pre-fabricated concrete elements
• 1000kr/m2
• 30 – 50 years lifetime
New solutions and materials

Many of the Nordic countries run different tests on new inner lining solutions.

It is experienced that durability and lifetime of the construction is strongly influenced by the level of cleaning. Material, structure of the surface and shape/design of the inner lining can often be a challenge for the cleaning of the tunnel. It is complex to find good solutions, and necessary to test thoroughly.

- Sprayed membranes
- Photo catalytic concrete
- Light concrete elements
- Composite panels
- Metal sandwich panels
- Sprayed rockwool
- Isolation material
We do not have the perfect solution yet

Research and development is needed

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