WATER INFILTRATION AND ICE PROBLEMS IN ROCK TUNNELS IN SWEDEN (AND THE NORDIC COUNTRIES)

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ABSTRACT

Operating and maintaining road tunnels during wintertime is connected to specific challenges/ problems. The lowest common denominator for these challenges is water which freezes during the cold period and consequently causes problems with ice, icicles, frost heave ("frost blasting") of concrete, shotcrete and also rock fragments. To meet these challenges, efforts can or has to be implemented according to the following;

A) Mitigate the water from entering into the tunnel and the tunnel portals (Design & Construction)
B) Ensure the function of installed drainage systems and the attached frost insulation in the vicinity of the tunnel (Maintenance)
C) Removal of ice and icicles as well as cleaning the tunnel (Operation)

KEYWORDS

WINTER / ROAD TUNNEL / WATER / ICE / OPERATION / MAINTENANCE

1. INTRODUCTION

With nine million inhabitants, Sweden is a small nation. But in terms of surface area, Sweden is a big country – the third largest in Western Europe – almost the same size as Spain and France. The large surface area and limited number of inhabitants make Sweden a sparsely populated country. Almost 90 percent of the population lives in the southern half of the country with a concentration to the areas around the cities of Stockholm, Gothenburg and Malmoe.

Sweden's northern location gives the country a cold climate which is tempered by the warm Gulf Stream running through the northern Atlantic Ocean. It is the Gulf Stream that makes it possible for people to live in Sweden. Areas at similar latitudes, like Canada, Alaska and Siberia, consist largely of harsh, uninhabited land.

Sweden do encounter winter climate which at some points can be quite cold and harsh. But in the southern part of Sweden, the winter climate is moderate with week-long periods (normally) of temperatures below zero with a number of temperature fluctuations around the freezing point. In the figure below, examples of the temperature in the Stockholm area during the winters 1993/94 and 1994/95 is depicted. The measured outdoor temperature for the winter of 1993/94 is shown with the thin dotted line while the measured temperature for the winter 1994/95 is shown with the thin line. Also, in the picture, the temperature design values for the Stockholm area, according to the national code for road tunnels (Tunnel 2004) is shown, where the small dotted line refers to the mean cold content and the thick dotted line refers to the maximum cold content.

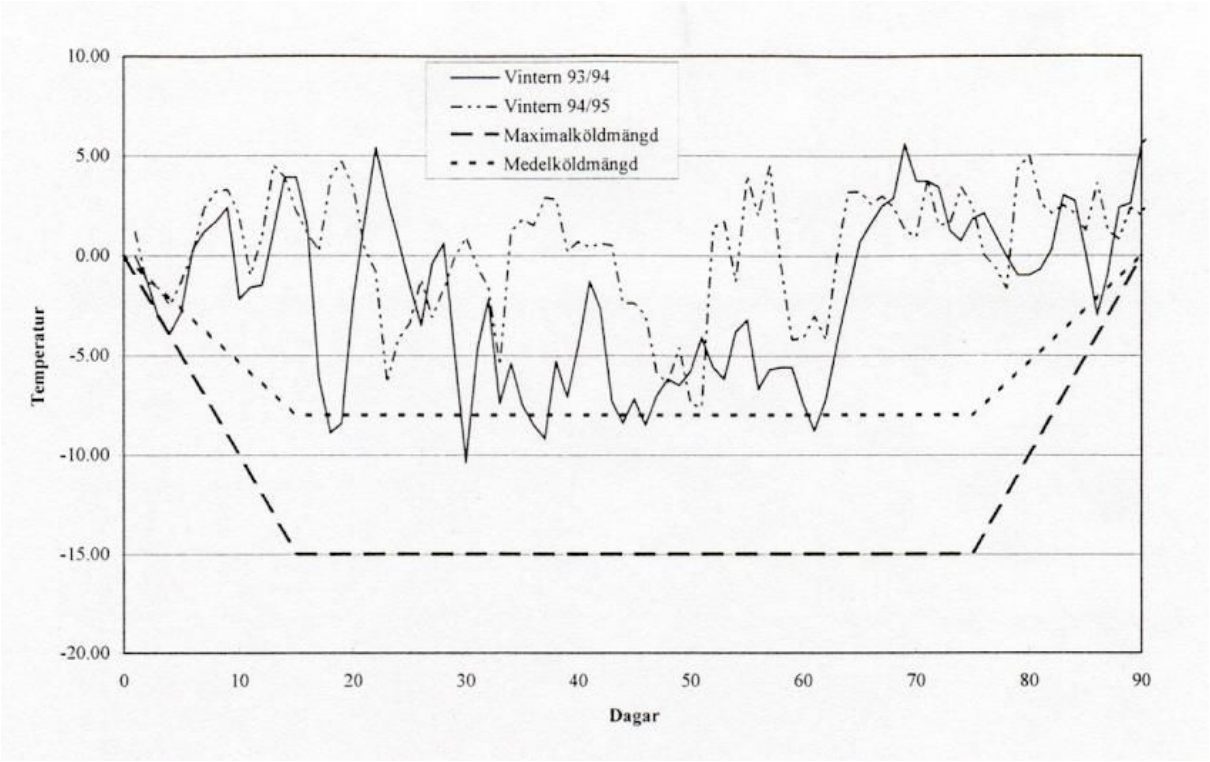

Figure 1- Measured temperatures during the winters 1993/94 and 1994/95 and temperature design values for the Stockholm area (Celsius degrees).

The Swedish road network comprises 98,400 km of state governed public roads and 41,000 km municipal streets and roads. In addition to the public roads there are about 76,000 km of private roads receiving state subsidies and a large number of private roads without state subsidies, most of which are forest roads. There are a total of about 16,000 bridges, 31 tunnels and 38 ferry routes on the road network. All roads and road structures on the state road net are managed by the Swedish Road Administration, SRA which has the responsibility for planning, construction, operation, maintenance and reconstruction. This responsibility includes ensuring that bridges and tunnels are inspected, damages are documented and remedial measures are planned and carried out. Many of these tasks are performed by external consultants and contractors. Facts on the SRA and the Swedish road net can be found at [1].

Sweden has a low number of road tunnels, in an international comparison, due to the fact that Sweden is not a particularly mountainous country and the low number of populated islands. The present road tunnels in Sweden are more or less concentrated to the areas around Stockholm and Gothenburg. Below, a compilation over the present road tunnels on the state road net is presented. At present, the total number of state governed road tunnels is 25 and the total length is about 45 km. More information on the Swedish bridges and tunnels can be found at [2].

The dominating construction type in Sweden is the reinforced rock tunnel without a supporting concrete or steel lining, although there are concrete tunnels present. The “Tingstad tunnel” in the centre of Gothenburg is an immersed tunnel crossing the Gotaalv River. The bedrock in Sweden mainly consists of rock of Precambrian age with good mechanical properties well suited for tunnel construction.

County	Name	Road nr	Length (m)	Lanes	AADT
AB	Fredhäll (TEN)	E4	200	4+4	140 000
AB	Häggvik	265	289	2+2	25 000
AB	N Länken Eugenia (TEN)	E4	235	2+2	85 000
AB	Södra Länken	75	4 500(1)	2+2	80 000
AB	Muskötunneln	539	2 960	2	1 700
AB	Lindö/Tappström	261	180	3	17 000
AB	Åkersberga	267	250		19 000
AB	Törnskogstunneln	265	2050	2+2	
AB	Löttingetunneln	265	1063	1+1	
O	Skultorp/Skövde	48	374	2+2	
N	Viskan(Åskloster) (TEN)	E6	265	2+2	10 000
O	Götatunneln (TEN)	E45	1600	3+3	65 000
O	Tingstadstunneln (TEN)	E6	454	3+3	100 000
O	Sörgård (Uddevalla)	44	210	2+2	16 000
O	Kärra (Uddevalla)	44	350	2+2	16 000
O	Gnistängstunneln	E6.20	712	2+2	35 000
O	Gårdsten	E6.20	415	2	13 000
O	Stenungsön	160	120	2	13 500
O	Vindön	160	485	2	5 000
O	Nösund/Boxvik	740	75	2	700
O	Lundby	E6.21	2 053	2+2	38 000
O	Grind (TEN)	E6	149	2+2	4 000
O	Jeriko	E20	110	2+2	27 000
Z	Åre (TEN)	E14	135	2	
Z	Stadsberg, Krångede	87	153	2	1 040

Figure 2 - Compilation over state governed road tunnels in Sweden. TEN = the tunnel is situated on a Trans-European-Road-Network. AADT = Average Annual Daily Traffic.

The older road tunnels in Sweden are mainly short tunnels with a comparatively low standard and were built in the countryside in order to give easy access to a number of populated islands and to obtain more efficient road stretches. The road tunnels being built during the last ten years are predominantly urban tunnels with a high technical and safety standard. This trend will, due to traffic congestion and lack of available surface areas, lead to construction of new urban road tunnels in the future.

The Swedish Road Administration has presented the Swedish general requirements and national standard levels regarding road tunnels in the document “Tunnel 2004” [3]. The tunnel regulations in Sweden of today conform to the common European standards and include the requirements of the EU directive on road tunnel safety. The specifications are structured according to the essential requirements in the CPD (the Construction Products Directive). All the regulations are available on internet but unfortunately only in Swedish.

With the limited number of road tunnels there are no standard construction classes available to apply, all tunnels are treated as unique objects calling for separate design and verification, due to the present conditions; AADT, type of traffic, depth in the ground, rock conditions etc.. There are, however, type solutions available on the construction element level. One requirement worth highlighting is that the prescribed service life of a road tunnel is 120 years.

A typical Swedish road tunnel is excavated with the conventional drill and blast technique according to the observational method. Prior to the drill and blast operation the actual rock mass is pre-injected with cement-based grout. After the blasting the remaining rock is supported, predominantly with steel rock bolts and shotcrete. Remaining water inleakage

is treated with post-grouting of cement- and/or chemical (resin-based) grout, combined with application of drains/ drainage systems.

Due to new environmental regulations, the protection of the groundwater levels and flow have been significantly strengthened in Sweden, thus putting rigorous demands for all construction activities below the groundwater level, including tunnelling works. These rigorous demands can - and often do, depending on the local groundwater conditions, - result in very harsh demands on the tunnelling activities. For example, in the completed road tunnel project “Gotatunneln” in Gothenburg the amount of in-leaking water to the tunnel was partly restricted to a maximum of 0,5 litres/minute and 100 meter!

2. PROBLEMS/ CHALLENGES RELATED TO ROAD TUNNEL OPERATION DURING WINTERTIME

The two main challenging areas related to road tunnel operation during the winter are;
Freezing of in-leaking water to the tunnel and/ or the tunnel portals, causing icicles hanging from the tunnel roof and walls as well as ice on the road surfaces, which are severe safety problems for road users as well as for operating staff. Ice and icicles on the tunnel walls are not considered to be a critical safety or technical problem as long as the ice/icicles do not affect the road surface by loosening ice debris.

The removal of ice and icicles in the Swedish road tunnels is a costly and a labour-intensive activity. During the cold period special attention is paid to the ice situation in the road tunnels during the continuous inspections performed. This activity is especially costly for the rural, remotely located tunnels where the operating personnel are in a situation with long travel distances between the operating centre and the specific road tunnel. In order to overcome this costly activity a new tunnel design, for Swedish standards, was tested at the “Tunnel vid Grind” opened a few years ago. This remotely located tunnel was completed with a thin secondary concrete lining including a water-proof membrane. Economic analysis prior to the design revealed that this concept with a higher initial investment cost would be more cost-effective than the conventional concept with no secondary lining but with a higher operating cost caused by the ice removal work. The experiences gained so far supports this analysis.

Another new concept with a stiff inner lining separated from the contour of the rock, covering the whole cross section, will be used in the “Norra Lanken” project to prevent water seepage into the traffic space. The use of such a lining makes direct inspection of the rock impossible. However, an investigation carried out by the SRA has shown that when the lining is fixed to the rock by bolts in a symmetric pattern with 1-1.5 m spacing these bolts will transmit any movement in the rock formation to the lining and this will cause the concrete inner lining to crack. An inspection of the inner lining thus would give information on the condition of the rock mass. If inspections indicate problems a detailed inspection will take place.

Cleaning of road tunnels when the temperature is below the freezing point. As the cleaning of the tunnel interior is performed with water-based solutions the use of such is impossible to execute. The lack of continuous cleaning operations during the cold periods are causing an internal environmental problem inside the road tunnels with potential dust and particle problems which can, at worst situations, cause sight problems for the road users.

For safety reasons, the traffic signs and safety devices (alarm, telephones, escape door handles, etc.) in and in the vicinity of the tunnels are always cleaned – by hand if needed.

At the Lundby tunnel, mechanical wipers have been installed to clean the lenses on the CCTV-cameras. So far the experiences have been positive, but the long-term costs for keeping the system functional over time have not been fully evaluated.

3. PROBLEMS/ CHALLENGES RELATED TO ROAD TUNNEL MAINTENANCE DURING WINTERTIME

The short- and long term maintenance of a road tunnel are normally not assigned to a specific annual period and is an ongoing striving work. Therefore, it is not really adequate to discuss specific winter challenges on the road tunnel maintenance.

Most of the maintenance activities are planned to be performed during the summer period, due to a number of reasons, for example normally less traffic and that the working conditions are more favourable during the summer period. The only maintenance activities normally performed during the winter period is the unplanned maintenance that has to be completed. An extensive report on how operation and maintenance of “Sodra Lanken” is implemented is presented in [4]. General challenging areas related to road tunnel maintenance are;

Water leakage into the tunnel and the tunnel portals. Water leakage is a severe problem inside the tunnel and/ or around the tunnel portals. Present water in connection with temperatures below the freezing point can initiate loosening of applied shotcrete causing potential safety problems due to falling particles on the road users. Another problem with freezing water is the potential risk of freeze-thaw expansion/ “blasting” of applied drains, which in turn can cause refurbishment of parts of the drainage systems installed. The normal procedure to treat water leakages is with post-grouting of cement- and/or chemical (resin-based) grout, combined with application of additional drains. If the water leakage is so immense that the surrounding groundwater situation is severely influenced, the need for temporary or permanent infiltration can be necessary.

The risk for freeze-thaw expansion/ “blasting” of applied drains/ drainage systems, is especially critical where conditions of chemical and/ or bacterial clogging are present. In some specific areas where the conditions are beneficial, severe problems are encountered with bacterial clogging, thus stopping the drainage function. The current bacteria of interest “Gallionella Ferruginea” is an iron-oxidation organism which flourishes in the tunnel environment and reproduces rapidly. To overcome this problem, investigations have to be performed in an early stage in order to identify the potential problem. If identified, the applied drains have to be designed so that they can be flushed at regular intervals. To overcome the problems with freeze-thaw expansion/ “blasting” of applied drains, installations of inner heating cables can be applied.

Corrosion problems in the road tunnels. The environment in road tunnels is very corrosive mainly due to the combination of de-icing salts and dirt. Gaseous pollution’s are judged to have a small influence. There is probably a direct relation between the intensity of traffic and the corrosivity inside a tunnel. High traffic intensity gives high corrosivity.

Regular cleaning has a very positive influence on the lifetime of the equipment inside a tunnel. If highly placed equipment’s are not cleaned they will, after some time, be exposed to an equally corrosive environment as equipment’s frequently cleaned and installed close to the roadway.

Results from the evaluation of numerous installed rock bolts showed that if the bolt installation is performed well, with complete cement cover, the corrosion resistance of cement casted rock bolts are high.

4. DESIGN FOR DURABILITY INCLUDING FROST RESISTANCE

Operating and maintaining road tunnels during wintertime is connected to specific challenges/ problems. The lowest common denominator for these challenges is water which freezes during the cold period and consequently causes problems with ice, icicles, frost heave ("frost blasting") of concrete, shotcrete and also rock fragments. General conclusions are;

- Water ingress strongly affects the durability of the structure and the installations
- In cold areas even very small water leakages will cause problems, such as icicles
- For rock tunnels pre-grouting of the rock mass is much more successful than post-grouting
- Due to the normally very high ground water pressure it is often very hard to repair leaking cracks

To overcome future problems as pointed out above, the most important issue is to have an initial, robust design philosophy when building new or refurbishing old road tunnels. The Swedish design code for road tunnels are based on predefined exposure classes related to corrosion and degradation due to identified and interpreted preconditions for the actual tunnel. Design for frost protection is performed based on actual and estimated outdoor temperatures and predefined "temperature design curves" coupled with precautious measures in order to secure that present water does not freeze.

For the future it is of utmost importance to evaluate the common practise how road tunnels have been and are designed and constructed in Sweden, predominantly in rock formations. At the moment two "new" (for Swedish conditions) road tunnel concepts with waterproof linings are being tested and evaluated. In the report [5] an overview of different inner lining solutions has been compiled by the Nordic Road Association.

For further development of road tunnel concepts, with the focus on water infiltration and frost insulation there are a number of questions that has to be penetrated;

- What is an acceptable amount of water drops per minute in a road tunnel?
- Watertight yes, but is it really a need for frost insulation?
- Is it possible to construct a watertight single lining of sprayed concrete?
- What is the best procedure to construct a concrete tunnel or lining without getting any cracks? Also for the sprayed concrete!

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