Insulation Against Ice in Railroad Tunnels

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Many of the tunnels and rock cuttings in the Swedish railway system are old and badly affected by frost action and frozen groundwater. This ice is a serious problem because in bad cases it may intrude on the track structure from the walls, and in periods of thaw it may loosen and fall on the track. It is therefore necessary to remove the ice. This work is both expensive and dangerous, and high costs and risks might be avoided if the seepage of water could be reduced or the water prevented from freezing. Deep drainage, widening the tunnel section, caulking with sprayed concrete, grouting, and insulation used to be used for this purpose. Since 1979 an entirely new method of insulating with cellular plastic has been used. Details of this method are discussed: choice of material, joining, installation and dimensioning, and cost. An account is given of the work that has been completed and of the results that have been achieved. Conclusions that may be drawn from experience to date are presented.

In 1984 the Swedish State Railways was using 95 tunnels and a large number of rock cuttings of various ages. Frozen groundwater in both tunnels and cuttings and ice columns on tunnel roofs make it necessary to undertake major and costly work in many places. The ice also causes "frost shattering," which leads to uncontrolled rock falls and damage to the concrete reinforcement. The ice can cause, and sometimes has caused, damage to both staff and rolling stock. Drops of water on power lines, rails, and sleepers mean more maintenance work and reduce the useful life of the installations. Figures 1–3 show how severe the problem can be.

Cutting the ice away is both a time-consuming and a thankless task that involves high safety risks. Daily inspections, even on weekends, and patrols of three or four men cutting ice every day are expensive, particularly if so much ice is cut that it must be carried out of the tunnel or cutting.

The problem has been dealt with in many different ways. It is necessary to prevent the water from freezing before it reaches the drainage structures in the bottom of the tunnel. Many old methods, for example casings, fir twigs, mats, and electrical heating, now have been replaced by insulation with flexible cellular plastic.

REQUIREMENTS OF THE INSULATION MATERIAL

To insulate a cutting or a tunnel effectively against frost, a material that meets the following requirements is needed:

1. Very low heat conduction coefficient.
2. Water repellent to the extent that its heat insulation properties are scarcely modified over a period of time.
3. Resistant to weathering, water-soluble elements, and sunlight.
4. Strong enough to withstand the slipstream of the trains, wind, and minor mechanical damage.
5. Sufficiently malleable to be adapted to blasted rockfaces.

PROPERTIES

The insulation material used by the Swedish State Railways is a malleable, extruded, cellular polythene plastic (Ethafoam 220 from Dow Chemical Company). At first the white variety of the material was used but now the black version is used because its resistance to destruction on exposure to sunlight is significantly higher. It is possible that a similar material [Neopolen 1712, manufactured by Badische Anilin- und Sodafabrik (BASF)] may also be used. The properties of the materials are given in Table 1.

Sheets of Ethafoam that measure 2.75 × 0.60 m and are 50 mm thick are available in black. The rigidity provided by the 50-mm thickness makes this material suitable for insulation. One layer is used in the southern and middle parts of Sweden, and two layers are used in the north.

JOINING

As mentioned earlier, the sheet measures 2.75 × 0.60 m and thus only covers 1.65 m^2. If water is seeping through large areas, the sheets have to be joined to form a continuous piece with a surface area as large as 140 m^2. The sheets are welded together in mats 2.75 m wide (Figure 4). The length is limited by considerations of transport and handling. These mats are

FIGURE 1 Frozen groundwater in the Åmål Tunnel.

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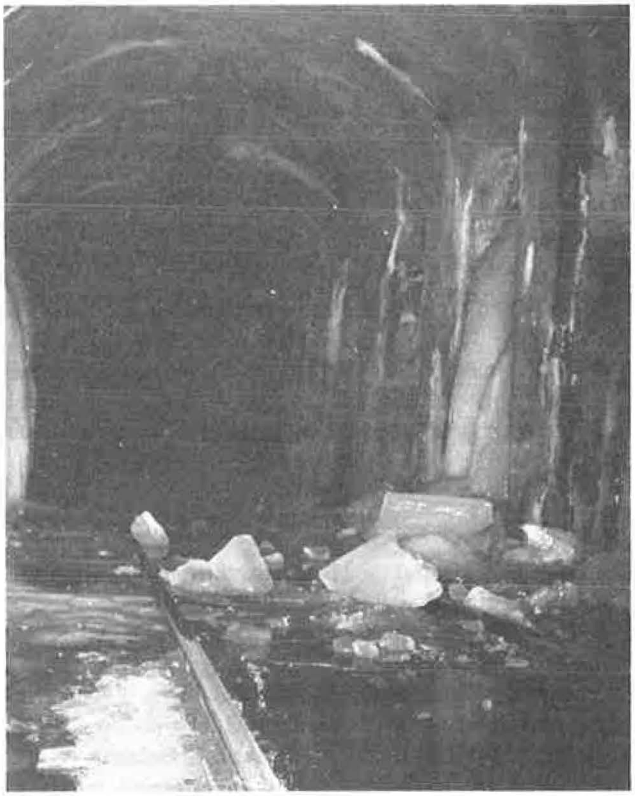

FIGURE 2 Ice fall in the Åmål Tunnel.

FIGURE 3 Concrete, cracked by ice, in the Liljeholmen Tunnel.

welded together on site with a hot-melt adhesive with a working temperature of approximately 170°C. Temperatures higher than 180°C destroy the mat. Meltex hot-melt adhesive equipment has been purchased and is shown in Figure 5.

TRANSPORTATION OF THE MATS

The prepared mats are transported from the bonding site to the mounting site by motor trolley (Figure 6), by sky-lift (Figure 7), or mounted on a truck with the mat hanging over the arm of the liftcage (Figure 8).

TABLE 1 MEAN VALUES ACCORDING TO DOW CHEMICAL AND BASF

Property (standard)	Unit	Ethafoam 220	Neopolen 1712
Density (DIN 53420)	kg/m^3	35	30
Load (DIN 53577) at			
10 percent compression	N/mm^2	0.035	
25 percent compression	N/mm^2	0.055	0.045
50 percent compression	N/mm^2	0.105	0.11
Deformation remaining after 24 hr recovery time (22 h, 50%, 23°C)	%	11	6
Tensile strength (DIN 53571)	N/mm^2	0.14	0.16
Elongation at fracture (DIN 53571)	%	90	55
Tearing resistance (DIN 54575)	N/mm^2	0.14	1.1
Water absorption over 24 hr (ASTM C-272)	% by volume	<0.5	<1.0
Steam permeability (DIN 52615)	μ-factor	>320	
Heat conduction coefficient at 25°C (DIN 52612)	W/mK	0.051	0.037

NOTE: DIN = Deutsches Institut für Normung.

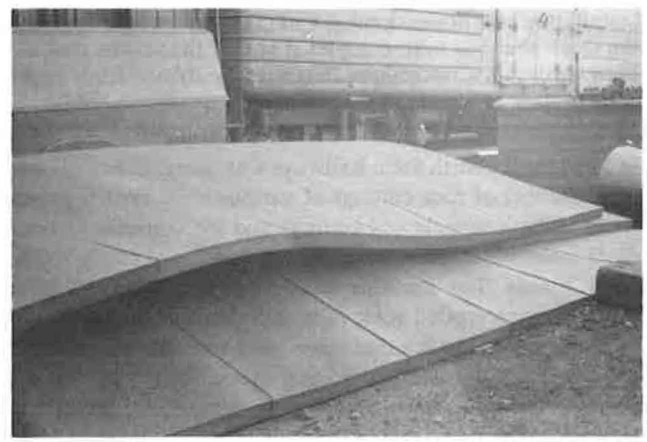

FIGURE 4 Ethafoam sheets glued together.

INSTALLATION

The mat is hung on the rock face by means of previously inserted bolts. The bolts have a fully threaded shank, are 12 mm in diameter, and are fixed to the rock with a chemical anchor (Figure 9). Drilling and setting one bolt takes only 3 or 4 min. A sky-lift is used for drilling and for hanging the mats (Figure 10). The mats are pressed manually against the wall. A more complete description of installation is given by Sandegren and Wallmark (*1*). Three installations are shown on Figures 11–13.

Costs

The 1982 costs of the material are given in Table 2.

WORK COMPLETED

Swedish Railways began insulating tunnels and cuttings with cellular plastic in 1979. Since then (end of 1986) 16 455 m of

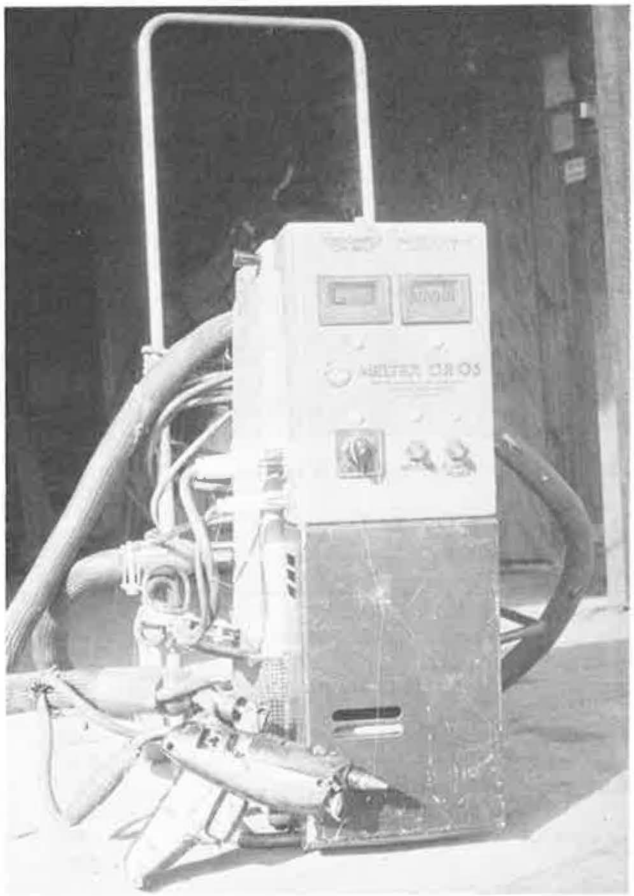

FIGURE 5 Equipment for bonding the sheets with hot-melt adhesive.

FIGURE 6 Transporting a mat with the aid of a trolley.

insulating mat have been installed. Table 3 gives completed and planned projects.

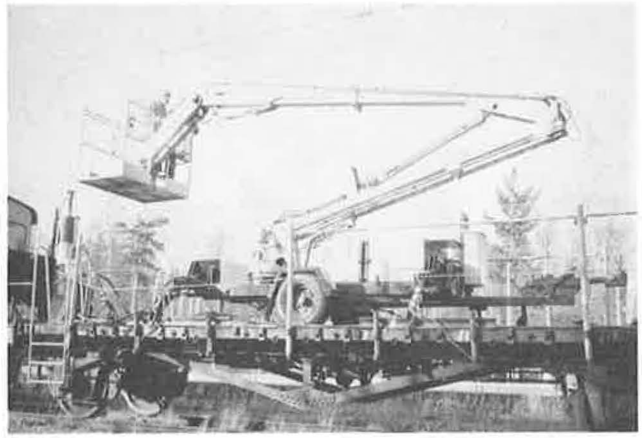

FIGURE 7 Sky-lift.

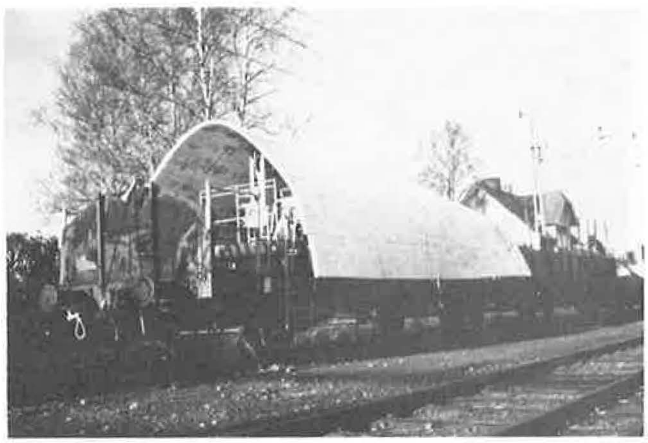

FIGURE 8 Transporting a mat with the help of a sky-lift mounted on a truck.

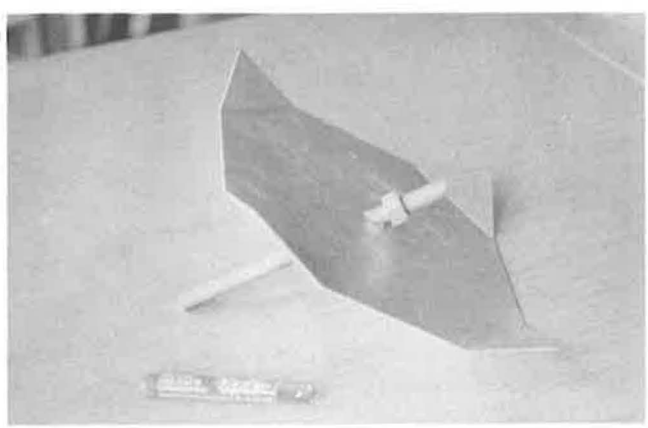

FIGURE 9 Chemical anchor, bolt, and washer plate.

RESULTS

By the winter of 1979–1980, Saetre (2) had shown by means of measurements that cellular plastic sheets provided effective insulation (Figures 14 and 15). However, when the idea was transferred to Sweden, the new material needed to be tried and a way of working with it, which was suited to the Swedish situation, had to be devised. Unexpected results, both negative and positive, were obtained before a viable method of installation was worked out.

Assessment of the projects that are now complete (Table 3) reveals that the results have exceeded expectations. However, a

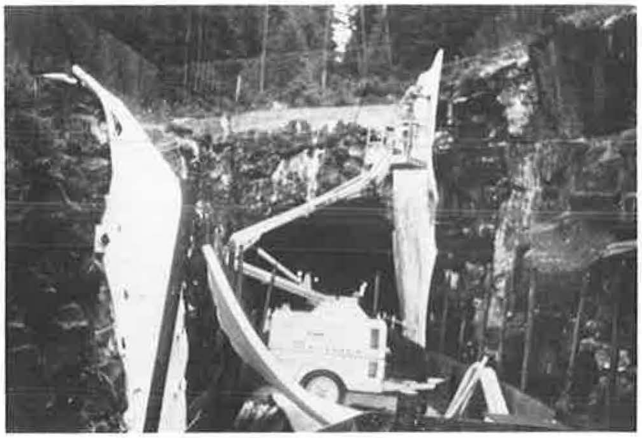

FIGURE 10 Installation of insulation with the aid of a sky-lift.

FIGURE 11 Installation in a cutting.

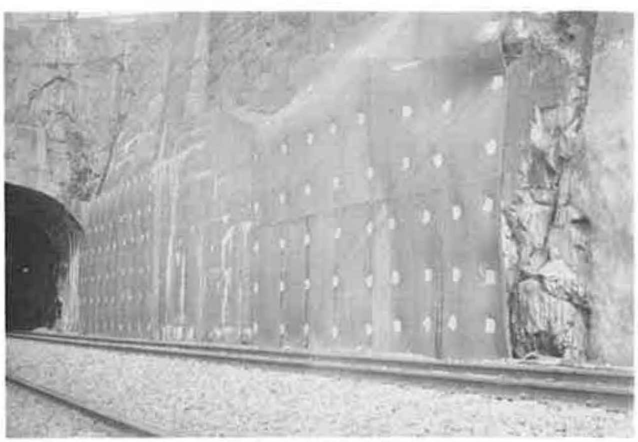

FIGURE 12 Installation in an opening.

number of things have been learned in the course of those projects.

At first 19-mm bolts fixed with a cotter key were used. In a few cases these bolts did not hold well, which meant that the mat hung down and caught on trains. Now 12-mm bolts, which are anchored with a chemical substance, are used. A great advantage of these slimmer bolts is that drilling can be done electrically.

FIGURE 13 Installation in a tunnel.

TABLE 2 COSTS

Material	SKr/Unit	SKr/m²
Chemical anchor (HKA 3), each	6.70	3.35
Bolt, 0.33 m with washer plate and nut, hot galvanized, each	16.50	8.25
Ethafoam 220, 50-mm loose sheets, m^3	1240	62^a 124^b
Hot-melt adhesive, 5 kg	360	1.40^a 2.80^b
Welding mats to form sheeting factory		21^a 42^b
Total per m^2		96^a 180^b
Working costs		
Bonding work		7
Setting bolts and hanging mats (3 hr/day)		145
"Normal" case		106
Total cost		$210–250^a$ $300–340^b$

[a]50-mm insulation
[b]100-mm insulation

Careful sealing around the edges of the mat to prevent the circulation of air behind the mats also proved to be important. In places where there is now insulation, it has seldom been necessary to cut down ice. In those cases in which ice removal has been necessary, only icicles have needed to be cut from places where the insulation was not tightly mounted.

Usually the insulation has paid for itself in 4 or 5 years, but the cost of reduced "wear" on the rock wall and the track stock has not been taken into account.

CONCLUSIONS

The following conclusions can be drawn after installation of approximately 15 400 m^2 of insulation:

1. Flexible cellular plastic can be used successfully to insulate tunnels and cuttings against frost.
2. The material should be ultraviolet stabilized.
3. The edges of the insulation must be carefully sealed, so that cold air cannot penetrate behind the insulation from the sides.

TABLE 3 CUTTINGS AND TUNNELS INSULATED BY THE SWEDISH STATE RAILWAYS

Railway line	Place	m^2	T=tunnel C=cutting
1979			
Kiruna-Vassijaure	Nuolja	200	T
Kil-Ludvika	Loka	250	T/C
1980			
Kiruna-Vassijaure	Tornehamn	30	T
Ludvika-Borlänge	Rämshyttan	170	C
Bjärka-Säby-Västervik	Gamleby	40	T
Göteborg-Borås	Landvetter	440	T/C
1980-81			
Stockholm-Uppsala	Hagalund Ö	2450	T/C
Stockholm-Södertälje	Södermalm	80	T
Limmared-Värnamo	Gnosjö	300	T/C
1981			
Härnösand-Långsele	Kramfors	720	T/C *
Stockholm-Uppsala	Hagalund V	250	T
Stockholm-Södertälje	Västberga	10	T
Katrineholm-Åby	Graversfors	950	T *
Göteborg-Borås	Hindås	700	T/C
1982			
Älvsbyn-Boden	Laduberg	200	T
Stockholm-Södertälje	Liljeholmen	1500	T
Borås-Limmared	Aplared	1800	T/C
Ulricehamn-Limmared	Åsunden	400	T/C
Uddevalla-Munkedal	Kärra I	350	T/C
Göteborg-Huddevalla	Skeppsviken	170	T/C
1983			
Härnösand-Långsele	Kramfors	80	T **
Ludvika-Borlänge	Rämshyttan	30	C **
Limmared-Värnamo	Brandsmo	200	T/C
Borås-Limmared	Aplared	200	T/C **
1984			
Ställdalen-Ludvika	Grängesberg	35	C
Fagersta-Ludvika	Vad	200	C
Stockholm-Södertälje	Rönninge	250	T
Södertälje-Järna	Ström	70	T
Göteborg-Borås	Hindås	400	T/C **
Katrineholm-Åby	Graversfors	80	T **
1985			
Kristianstad-Karlskrona	Pengaberget	860	T
Halmstad-Getinge	Skogby	690	T
Halmstad-Getinge	Margretetorp	910	T/C
1986			
Halmstad-Getinge	Skogby	1100	T **
	Margretetorp		
Hässleholm		260	C
Limmared-Värnamo	Gnosjö	80	T **
	Total 1986	16455 m	
Planned 1987 and later			
Göteborg-Borås	Hindås	200	T **
Göteborg-Uddevalla	Six tunnels		T/C
Halmstad-Getinge	Skogby	550	T **
	Margretetorp		
Stockholm S-Hammarby-hamnen	Södersjukhuset	800	T
Mellerud-Kornsjö		500	C

* = three tunnels

** = adding work

FIGURE 14 Sealing along the edge of the mat with mineral wool.

4. The material is flammable, so great care must be taken when installing it to ensure that water seepage or ice formation cannot produce a spark-over from the overhead power line.

5. The cost of cutting ice is normally so great that the cost of installing insulation can be amortized over a few years, which makes the treatment economically viable.

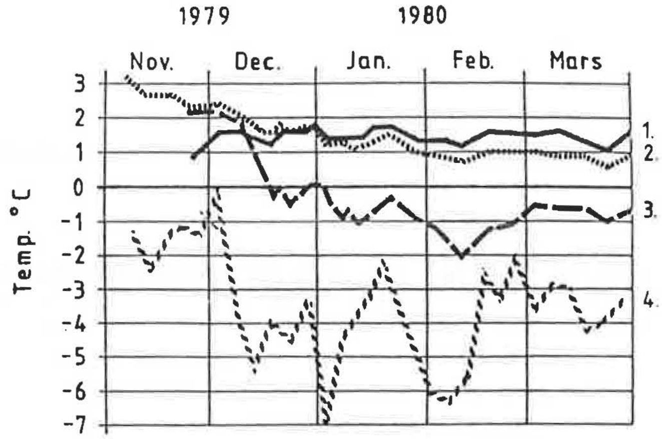

FIGURE 15 Measurements of the temperature in the Högberget Tunnel according to Saetre *(2)*: 1. = temperature on the rock face behind 70 mm insulation; 2. = temperature on the rock face behind 50 mm insulation; 3. = temperature 1.0 m into uninsulated rock; and 4. = 5-day mean temperature of tunnel air.

REFERENCES

1. E. Sandegren and G. Wallmark. *Isolering mot svallis i tunnlar och skärningar* (Insulation Against Ice in Tunnels and Cuttings). English translation by Dow Chemical, undated.
2. K. Saetre. *Frostsikring av tunneler, isolering med Ethafoam.* Report GK 2531. Norges Statsbaner, Geoteknisk Kontor, Oslo, Norway, 1980.