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ENVIRONMENTAL EFFECTS OF CHEMICAL DE–ICING

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ABSTRACT

The paper presents results and conclusions from studies concerning environmental effects of chemical de-icing in Sweden from 1978 and onwards. Studies have been carried out in a number of test areas along rural roads in the western and central parts of Sweden. All test areas have been kept under observation for two years and in some areas follow-up studies have been made after ten years. Water samples have also been collected from a surface water supply situated very close to a motorway. The aim of this study was to determine salt concentrations at different levels and examine whether the water circulations was affected by the use of chemical de-icing or not. Salting was suspended on the roads and streets of the island Gotland from winter 1986/87 onwards. In that connection a study has been conducted as a before-and-after study, with the natural environment in some test areas being documented both before and after the suspension of salting.

Cet exposé présente les résultats et les conclusions d'études concernant les effets du dégivrage chimique sur en Suède depuis 1978 jusqu'à présent. Des études ont été réalisées dans un certain nombre de régions test le long des routes rurales à l'ouest et au centre de la Suède. Toutes les régions testées ont été sous observation pendant deux années, et dans quelques régions des études de suivi ont été effectuées dix années après. Des échantillons d'eau ont également été recueillis d'un système d'alimentation d'eau en surface très proche de l'autoroute. L'objectif de cette étude était de déterminer les concentrations de sel à différents niveaux et d'examiner si la circulation de l'eau était affectée ou non par l'utilisation du dégivrage chimique. L'épandage de sel a été suspendu sur les routes et les rues de l'île de Gotland à partir de l'hiver 1986/87. Dans ce contexte, une étude a été réalisée comme étude avant-après, l'environnement naturel étant documenté dans certaines régions-test avant et après la suspension de l'épandage du sel.

In diesem Vortrag werden Resultate und Schlußfolgerungen von Studien präsentiert, welche die Umweltauswirkungen chemischer Enteisungsmaßnahmen in Schweden zum Thema hatten. Diese Studien wurden in einer Reihe von Testgebieten entlang Landstraßen im westlichen und mittleren Teil Schwedens durchgeführt. Alle Testgebiete wurden zwei Jahre lang beobachtet, und in einigen Gebieten wurden nach zehn Jahren nachfassende Studien durchgeführt. Es wurden auch Wasserproben von einem Oberflächenwasservorkommen in unmittelbarer Nähe einer Autostraße gezogen. Der Zweck der Studie bestand darin, die Salzkonzentration auf verschiedenen Ebenen zu bestimmen und zu untersuchen, ob der Wasserkreislauf durch die Verwendung von chemischen Enteisungsmaßnahmen beeinträchtigt wurde oder nicht. Die Salzstreuung wurde auf den Straßen und Wegen der Insel Gotland ab Winter 1986/87 eingestellt. In diesem Zusammenhang wurde eine Untersuchung in Form einer Vorher-Nachher-Studie durchgeführt, wobei die natürliche Umgebung in einigen der Testgebiete sowohl vor der Einstellung der Salzstreuung als auch danach dokumentiert wurde.

Environmental Effects of Chemical De-icing

In Sweden, chemical deicing with sodium chloride has been used since the mid-60s. Throughout this period, there has been debate on the advantages and disadvantages of salting roads in winter. The negative effects of the salt on the sourrounding natural environment have frequently been cited as an argument against winter salting and several studies of these problems have been conducted. In one such study, the Swedish Road and Transport Research Institute (VTI) was commissioned by the National Road Administration to perform a relatively extensive analysis of the environmental impact of winter salting, in which a number of test areas were set up along rural roads in southern and central Sweden. Within these areas, which were monitored continuously for about two years, the following investigations were made:

- Surveying of the geological and hydrological conditions.
- General analysis of vegetation.
- Repeated sampling of soil, ground water and vegetation (coniferous). Analysis of samples with regard to sodium and chloride concentrations.
- Calculation of salt quantity spread.

The test areas showed more or less extensive influence from road salt, both in the form of damage to vegetation and in raised levels of salt in soil, ground water and vegetation. However, there was no clear and simple relation between the salt quantities spread on the roads and the salt concentrations occurring in the surrounding natural environment. A certain quantity of salt in one area could give rise to high salt concentrations and damage to vegetation, for example, while the same quantity in another area had no measurable impact. However, one decisive factor for the degree of influence from salting was found to be the geological and hydrological conditions (figure 1). The areas most affected by salting were characterised by a flat topography, high ground water level and a slow rate of water replacement.

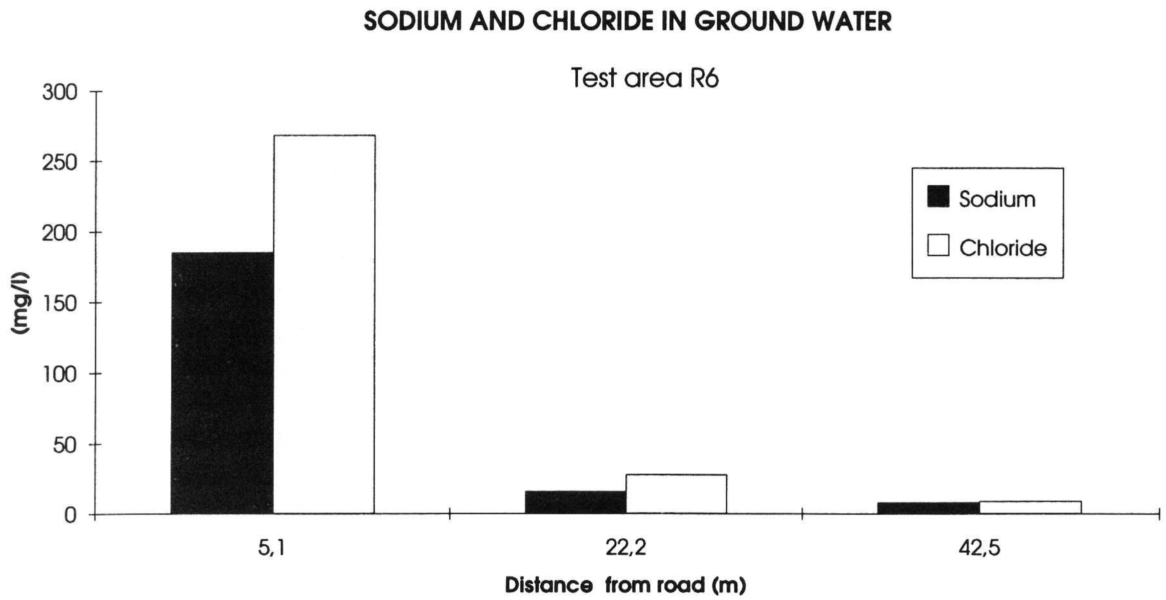

Figure 1. Sodium and chloride concentrations in ground water at test area R6 which was considered to have unfavourable geological and hydrological conditions.

In some test areas, relatively extensive damage to vegeation was found. This was also considered to be the most common and tangible effect of salt spreading. Coniferous trees in particular showed more or less extensive damage along salted roads. However, damage to vegetation was usually limited to a 10 metre wide zone along the roads and the area of forest that may have been damaged is therefore small.

To study the long-term effects of salt spreading, various follow-up observations were made after about ten years. These included taking new samples of soil and ground water in three of the test areas. The results of these samplings generally confirmed the conclusions from the earlier investigations that geological and hydrological conditions are decisive in regard to the degree of influence from salting. Thus, one of the areas considered to have favourable geological and hydrological conditions was unaffected by salting, while two other areas considered to have unfavourable conditions showed continued high salt levels. In one of the areas, the level was higher both in the ground water and the soil (figure 2). Therefore, it appears that an accumulation of salt had taken place, probably as a result of the very slow rate of water replacement in the area.

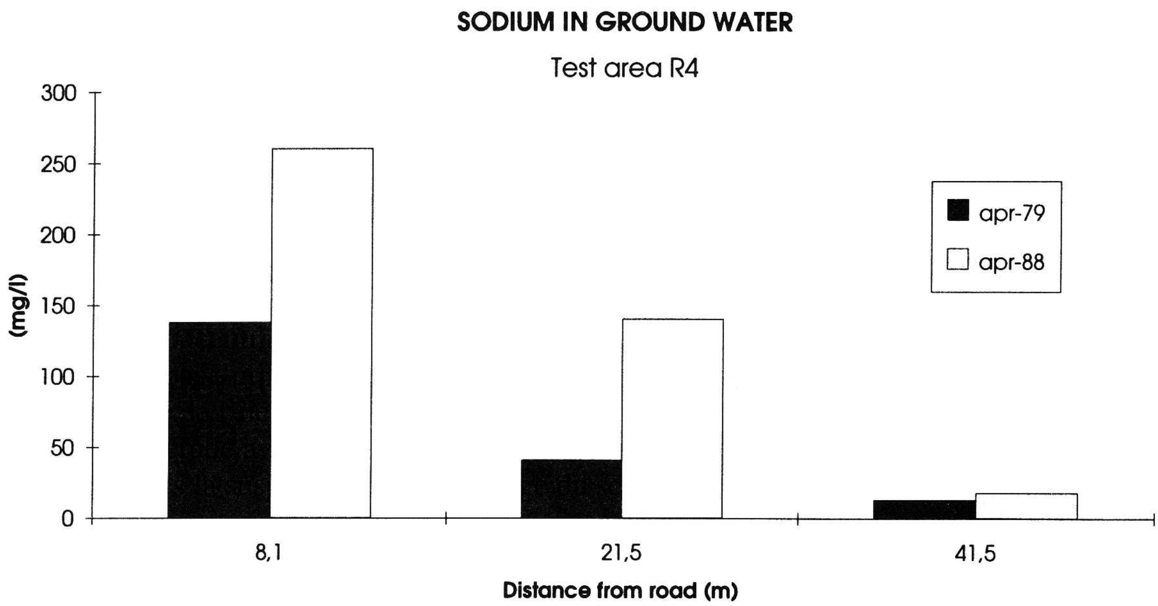

Figure 2. Sodium concentrations in groundwater at test area R4 in april 1979 compared with april 1988.

To study whether the ground water supplies close to salted roads were affected by salt spreading or not, analytical data on chloride levels were obtained from a number of municipal water treatment plants. In some cases, the results showed chloride levels increasing with time. However, the levels remained relatively low and were far from critical.

Based on Swedish experience, the risk of ground water supplies being polluted is therefore considered small. The known cases of ground water supplies that have been polluted concern water near ground level and very close to roads, as well as lying in permeable types of soil. Owing to their volume and water replacement rate, the major formations (such as large glacio-fluvial deposits), often containing large ground water supplies, are considered relatively insusceptible to pollution by road salt.

Water samples have also been taken from a surface water supply (a lake) close to a motorway. The results showed that the influence of road salting was marginal with consideration to the fairly small volume of the lake. The measured salt levels were comparatively low and the water circulation in the lake was not thought to be affected. The levels were also fairly close to the theoretical maximal levels, which were calculated with the aid of a simple model.

In order to investigate the consequences for road users, the environment and road maintenance authorities when an entire region is left free of salt, salting was suspended on the roads and streets of the island Gotland from winter 1986/87 onwards. To determine the influence on the natural environment, a number of test areas were set up. In these areas a study was conducted as a before-and-after study, with the natural environment in these areas being documented both before and after the suspension of salting.

Samples of soil and vegetation were taken in all the test areas. In some areas, pipes were driven into the ground to obtain samples of the ground water. The samples were analysed for sodium and chloride concentration, as well as pH value.

The results of the analyses showed that the areas generally demonstrated limited influence from road salting. This was probably because salt usage on Gotland has been less extensive than on the mainland. Nonetheless, it was possible to document a certain influence from road salting in all the areas. In at least two of the areas, it was also possible to demonstrate a effect of the suspension of salting in the form of reduced salt concentrations in ground water and soil (figure 3).

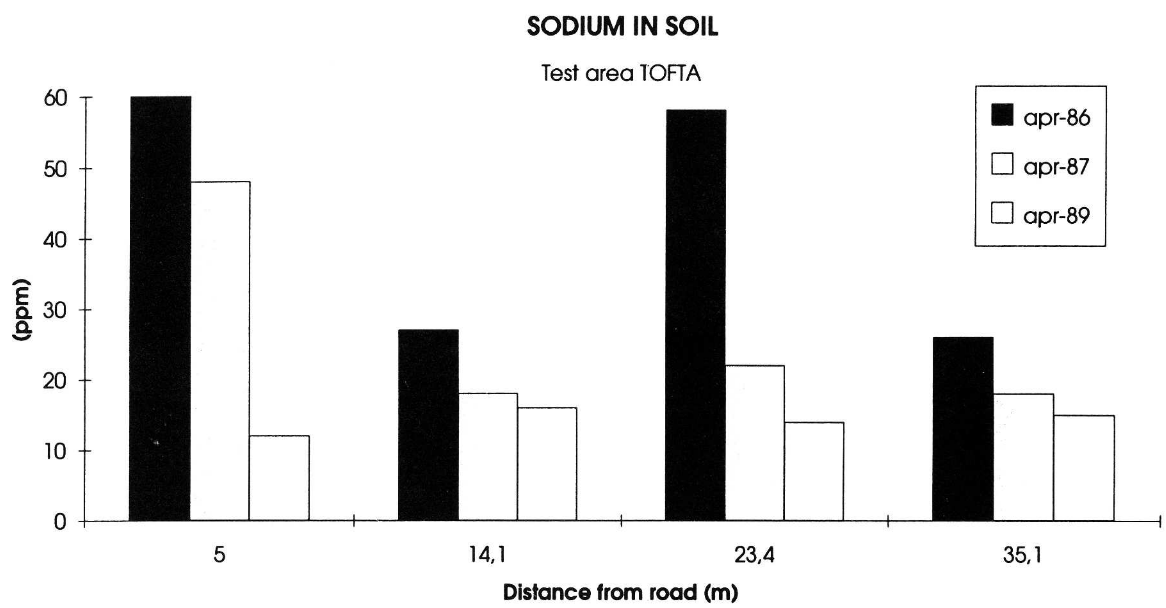

Figure 3. Sodium in soil at test area Tofta. Salting was suspended from winter 1986/87 onwards.

Based on swedish experience the following conclusions concerning environmental impact of chemical de-icing can be drawn:

Highway de-icing using sodium chloride may cause raised salt levels in soil, vegetation and groundwater along rural roads. During certain conditions this can also lead to damages to vegetation and to pollution of ground water. Therefore it is, from a strictly environmental point of view, desireable that efforts are made to restrict the use of sodium chloride. However, from an economical point of view and considering the costs for alternative de-icing methods, it is held, that the environmental impact due to the use of sodium chloride is marginal.

In urban areas, however, the impact may be more serious due to the fact that the vegetation often is very close to the roads/streets and that larger amounts of salt are spread.

SUSCEPTIBILITY TO ICING ON DIFFERENT ROAD PAVEMENTS

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ABSTRACT

Swedish Road and Transport Research Institute has conducted investigations with the aim of assessing the susceptibility to icing on various pavements in wintertime and the influence on deicing measure. Conventional wearing courses, dense asphalt concrete and surface dressings, as well as less common wearing courses, porous asphalt, RUBIT rubber asphalt and Verglimit were included. Skid resistance measurements and visual observations have been performed in varying weather and road surface conditions for several winters. The studies reported in this paper have shown:

- a coarse texture is in many cases favourable from the point of view of skid resistance in wintertime.
- porous asphalt pavements are generally somewhat less skid-resistant and require more extensive de-icing measures than conventional dense asphalt concrete.
- Verglimit and RUBIT have shown to have a skid-preventive effect in some situations, these situations were however relatively few.

L'Institut suédois de recherche sur les routes et les transports a effectué des recherches visant à déterminer les risques de verglas sur divers tapis routiers en hiver et l'influence sur les mesures de dégivrage. Ces recherches traitent les couches de roulement conventionnelles, le béton bitumineux dense et les traitements de surface tout comme des tapis moins communs comme l'enrobe drainant, l'asphalte caoutchouc RUBIT et Verglimit. Des mesures de résistance au dérapage et des observations visuelles ont été réalisées dans des conditions météo changeantes et dans des conditions de surface routière variées pendant plusieurs hivers. Les études traitées dans cet exposé ont montré que :

- une texture grossière est, dans nombre de cas, favorable du point de vue de la résistance au déparage en hiver.
- des tapis en enrobe drainant présentent généralement une moindre résistance au dérapage et requièrent des mesures de dégivrage plus intenses que le béton bitumineux conventionnel dense.
- Verglimit et RUBIT se sont révélés avoir un effet anti-dérapage dans certaines situations, toutefois assez rares.

Das schwedische Straßen- und Transportforschungsinstitut hat Untersuchungen mit dem Ziel durchgeführt, die Vereisungsanfälligkeit verschiedener Straßenbeläge im Winter und den Einfluß von Enteisungsmaßnahmen festzustellen. Dabei wurden konventionelle Verschleißdecken, dichter Asphaltbeton und Oberflächenüberzüge sowie weniger häufige Verschleißdecken, Drainasphalt, RUBIT-Gummiasphalt und Verglimit untersucht. Anti-Schleuder-Maßnahmen und visuelle Beobachtungen wurden über mehrere Winter hinweg unter unterschiedlichen Wetter- und Straßenoberflächenbedingungen durchgeführt. Die in diesem Vortrag beschriebenen Studien haben folgendes gezeigt:

- eine rauhe Oberflächentextur ist im winter vom Gesichtspunkt der Griffigkeit in vielen Fällenvorzuziehen.
- Drainasphaltbeläge sind im allgemeinen etwas weniger griffig und erfordern umfassendere Enteisungsmaßnahmen als konventioneller dichter Asphaltbeton.
- Verglimit und RUBIT haben in bestimmten Situationen nachweistlich griffige Eigenschaften, wobei diese Situationen jedoch relativ selten auftreten.

Introduction

The friction characteristics of different wearing courses when dry and wet are fairly well known. On a wet road, skid resistance at higher speeds is appreciably lower on a smooth and polished surface than on a rough and harsh surface, which is of great importance in regard to aquaplaning. In other words, surface dressing and porous asphalt are wearing courses which are positive from the aspect of wet friction. The skid resistance at different speeds on wet surfaces can be seen in figure 1 for surfaces with different macro and micro texture.

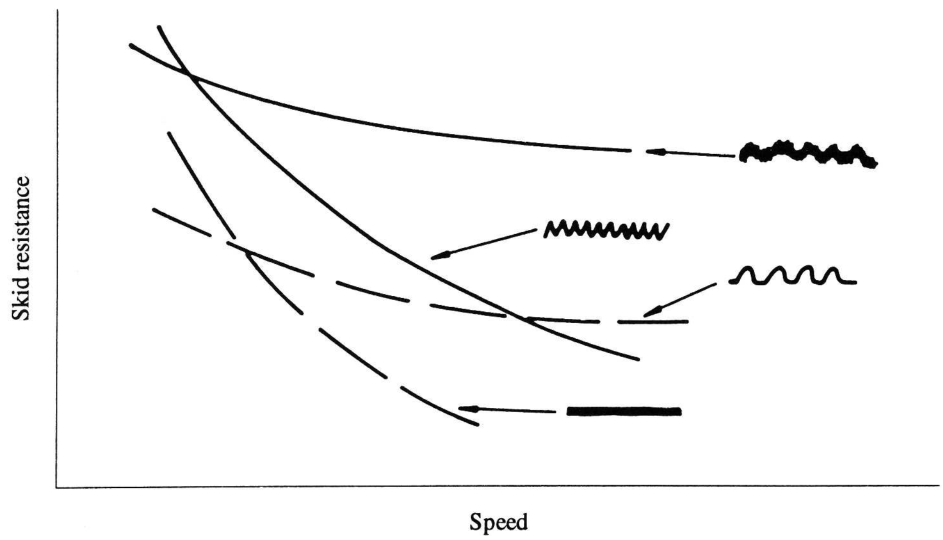

Figure 1. Coefficient of friction at different speeds on a wet surface.

On the other hand, the way friction varies on different wearing courses in winter conditions has not been studied to the same detailed extent. However, through Swedish studies in different projects in the 80'ies and the beginning of the 90'ies it has been possible to document skid resistance during different winter road conditions. Included in these studies were conventional wearing courses such as dense asphalt concrete and surface dressings as well as less common wearing courses such as porous asphalt, RUBIT rubber asphalt and Verglimit (asphalt mixed with salt).

This paper describe the studies, the results from measurements on different wearing courses and gives a view of the susceptibility to icing on different surfaces. Some aspects on winter maintenance on different wearing courses will also be given.

Four different studies

At the request of the Swedish National Road Administration, the VTI has conducted investigations with the aim of assessing the susceptibility to icing on various pavements in wintertime and the influence of the wearing course on deicing measure. Skid resistance measurements and visual observations have been performed under varying weather and road surface conditions for several winters. The following studies have been made:

- A 3-year study on a 4-lane motorway at Nyköping with dense asphalt concrete, surface dressings, porous asphalt , rubber asphalt and Verglimit.
- A 3-year study on a 2-lane road at Linköping with dense asphalt concrete, porous asphalt and surface dressings.
- A 3-year study on a 4-lane motorway at Glumslöv with dense asphalt concrete, RUBIT rubber asphalt and Verglimit.
- One winter follow-up on a 2-lane road at Öjebyn comparing RUBIT rubber asphalt and stone mastix asphalt.

Dense asphalt and surface dressings

Asphalt pavement, such as dense asphalt concrete (AC), generally offers good skid resistance on a bare surface, although this deteriorates when wet, especially when the surface is very smooth. Friction in conditions of snow and ice is often poorer than on wearing courses with a coarser texture, such as relatively new surface dressings. In some cases, however, a smooth asphalt pavement may offer better friction than coarser types of wearing courses since it is easier to clear from ice and snow.

The texture of the surface-dressed sections in the study differed owing to type, age and wear. It has thus been possible to study the relation between texture and winter friction, but only to a limited extent because of pavement wear, esp. from the use of studded tyres. However, in general the friction measurements showed that a coarse texture in many cases was positive from the aspect of slipperiness in wintertime. This was particularly noticeable when the surface dressings were new and coarse. However, the positive effect on friction in a comparison with asphalt pavement diminished with increasing smoothness of texture. In this case, this effect was noticeable already after one winter, but under more normal traffic conditions the improvement in friction on surface dressings compared to asphalt concrete should remain for a longer time.

In figure 2 is shown a comparison, a summary, of the skid resistance in slippery conditions on a smooth asphalt concrete and a course surface dressing during one winter. Each measurement are made about the same time on the two surfaces and they include recordings both before and after deicing mesures. The lowest skid resistance has generally been present on the smooth asphalt concrete. The surface dressing has no registration of skid resistance lower than appr. 0.3 while the asphalt concrete has several lower than 0.2. This result clearly shows that a course macrotexture is favourable, not only for skid resistance in wet conditions, but also in winter conditions with snow and ice.

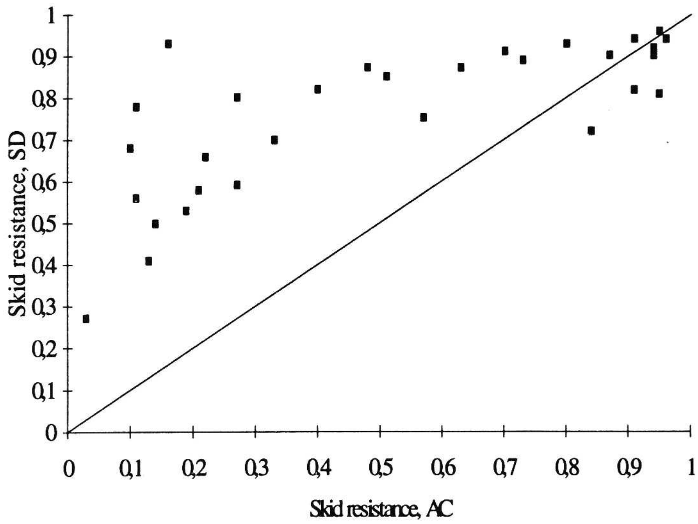

Figure 2. Skid resistance during winter conditions. Comparison between a dense asphalt concrete AC (smooth) and a surface dressing SD (rough).

Porous asphalt

Porous asphalt concrete has several favourable properties, such as improved dewatering of the surface, (less danger of aquaplaning), reduced splashing and spray from vehicles, noise reduction and better reflectivity in the dark. In the winter, however, porous asphalt displays somewhat less favourable characteristics. The special conditions and characteristics reported in the literature are

- the thermal conductivity is lower which result in more rapid and deep temperature drop during autumn and winter
- the thermal sensitivity can lead to earlier formation of ice and hoarfrost
- the time salt is staying on the surface is very short as a result of the high voids content
- the surface can stay wet longer and condensation can take place due to moisture in the voids
- snow and ice can stick more easily to the surface
- there is no splash effect, horizontal movement by traffic, of salt brine

The special conditions on drain asphalt surfaces were seen during the winter studies on a local road near Linköping and VTI. This road has an average daily traffic of appr. 4000 – 6000 vehicles per day and maintenance operations include chemical deicing.

The porous asphalt section was, due to its open structure with high voids content, more susceptible to icy conditions in wintertime compared to conventional dense asphalt. In some of the situations that was followed it was shown that the formation of ice and hoarfrost was starting earlier and was more intense on the open graded surface. This is mainly due to the open structure which gives the porous asphalt lower thermal conductivity and a faster temperature drop in radiation situations, cold and calm weather with clear sky. A situation like this is shown in figure 3.

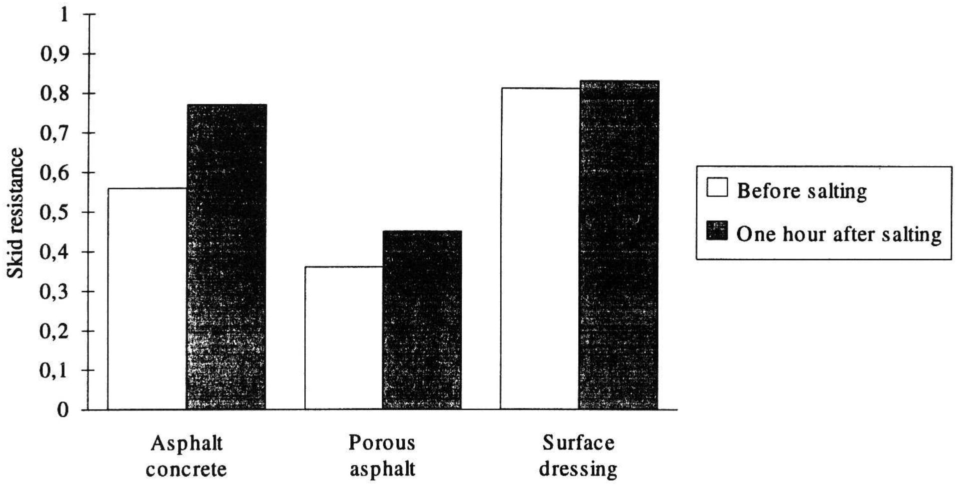

Figure 3. The skid resistance on sections of dense asphalt concrete, porous asphalt and surface dressing in a winter situation with hoar frost.

In figure 3 the skid resistance on three different wearing courses, dense asphalt, porous asphalt and surface dressing, one morning with hoarfrost formation is shown. The skid resistance was measured at appr. 6.30 and 9.00 a m and between these measurements salting was performed at appr. 8.00 a m. The temperature was a few degrees below 0°C and the weather was clear. Hoarfrost had formed, mostly on the porous pavement. From the figure it can be seen that the porous asphalt has low skid resistance before the salting measure and that it`s only a little higher one hour after the chemical deicing. The dense asphalt concrete has somewhat lower skid resistance early in the morning due to some hoarfrost formation. After salting bare pavement level is reached and this shows that the icy conditions was not severe. On the course surface of the surface dressing the skid resistance is very high from the beginning and there is no slipperiness due to ice or hoarfrost formation.

The situation above shows that porous asphalt is more susceptible to icing and that salting is not as effective as on the other pavements. The latter is due to the fact that more ice is formed resulting in thicker layer and that the salt brine is drained off. In the described situation the surface temperature on the different pavements was also recorded. The registration showed that the temperature was lower, appr. 0.5 to 1°C, on the porous surface compared to the others.

The higher susceptibility to icing on porous asphalt has also been documented in some situations with snow fall. However, in the beginning of a snow storm and during light snow fall the porous asphalt could have good skid resistance as long as the rough surface gives contact to the tyres through the snow layer. If the snow fall continues the snow will be packed in the porous surface and the skid resistance will be lower. Figure 4 shows a picture taken after a snow fall situation very late in the winter. The road keeper was taken by surprise and therefore salting was performed very late in the morning , appr. at 8.00 a m. The snow had fallen earlier in the morning and it stopped about the time of spreading. The picture shows the difference in road condition between the dense asphalt and the drain asphalt appr. two hours after salting. There is still much snow and slush left on the open graded pavement while the dense pavement has a wet, but bare, surface.

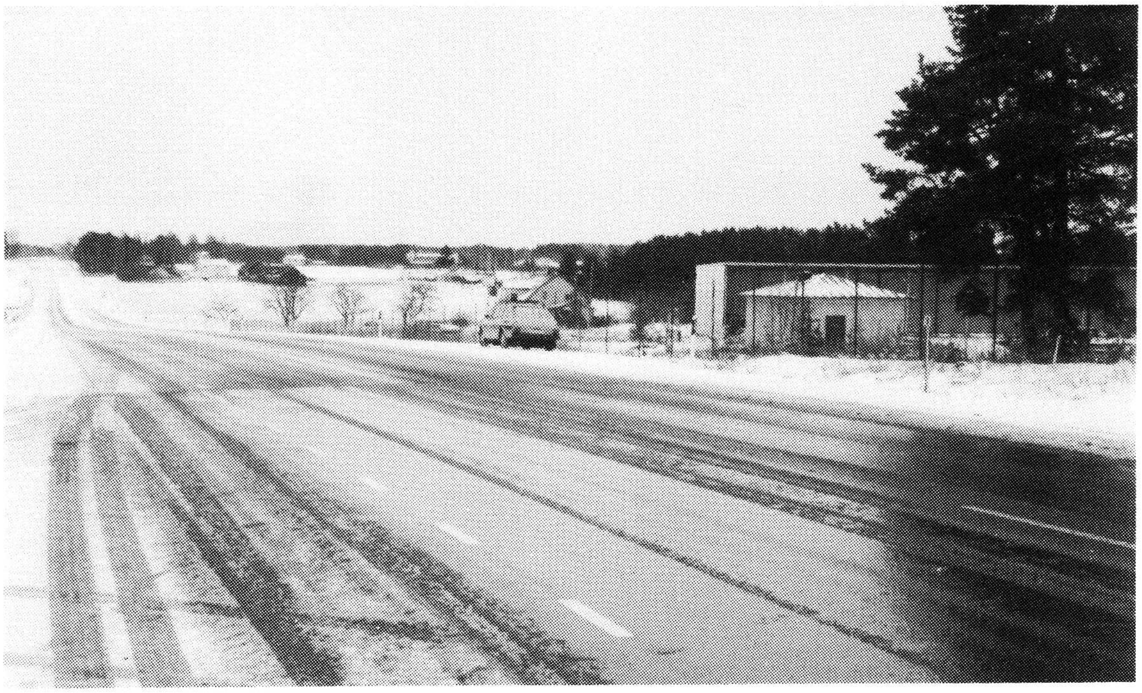

Figure 4. The difference in surface condition between sections of dense asphalt in the foreground and porous asphalt after a snow fall and salting.

The difference between the two surfaces in this snow fall situation can also be seen in figure 5 where skid resistance measurements are shown. Bare pavement values were recorded on the dense asphalt while the coefficient of friction was much lower on the porous surface. At the first registration it was especially low but it got higher due to ploughing and the mechanical effect of traffic.

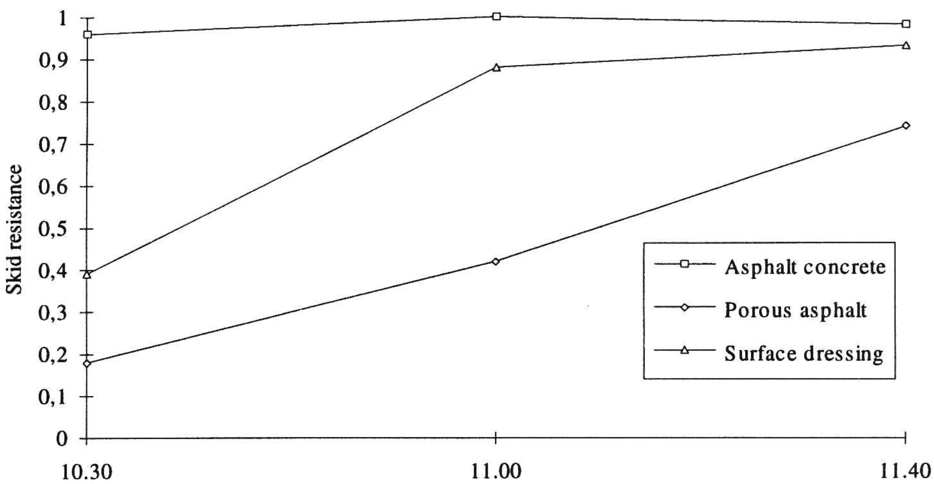

Figure 5. The skid resistance on sections with porous asphalt, dense asphalt concrete and surface dressing in a snow fall situation.

The susceptibility to icing on porous asphalt has also been studied by SNRA on E6 motorway in the south of Sweden. This particular section of the road was resurfaced in the summer of 1983 and already the first winter there were maintenance problems, especially in connection with snow falls. According to the maintenance personel there was a clear boundary line of standard between the porous asphalt and the dense asphalt. This difference of standard level could sometimes last up to 24 hours after a snow fall or icy situation.. To achieve the same level of standard the porous asphalt had to be salted one or two times more than on the dense asphalt sections.

During the winters 1984-1986 pre-wetted salt was used for chemical deicing and at the same time the road conditions were studied by skid resistance measurements and visual inspections. The results verified that there are differences in standard between porous and dense asphalts. With dry salt it could take up to 24 hours before the slow moving lane on the 4-lane motorway was free from snow and slush. With pre-wetted salt there was a more rapid effect but not as fast as the effect on the dense asphalt. In connection with snow or slush on the road the skid resistance increased more rapidly on the dense asphalt surface than the drain asphalt due to the better action of the salt with traffic. The salt was spread horizontal over the surface by the influence of traffic, while the salt brine was drained into the pores and to the road side of the porous surface.

Skid–resistant pavements

To reduce the risk of skidding at more exposed places, tests have been carried out for many years with pavements to which rubber or salt particles have been added. The two types of pavements are rubber asphalt (RUBIT) and asphalt concrete with a salt additive (Verglimit).

A common rubber proportion in RUBIT is about 3 % by weight of granulate (1–4 mm) and a smaller proportion of powder (0–1 mm). The rubber particles are produced by grinding down old vehicle tyres. Verglimit, which consists mainly of calcium chloride ($CaCl_2$), is added to conventional asphalt concrete pavements. A common admixture of Verglimit is 5–6 % of the total weight of the pavement, but 3,5 % may be sufficient on roads with dense traffic and a high proportion of studded tyres.

To study more closely the characteristics of RUBIT and Verglimit, and in particular their possible skid-prevention properties, test stretches were prepared on a motorway in the south of Sweden in the summer of 1987. Comparison was made to an ordinary asphalt concrete (AC). The test programme included a technical evaluation of the pavement's composition, properties and quality and also an intensive follow-up of its frictional properties in the winter to determine its skid-prevention, if any.

The study showed that all three pavements were stable and not prone to deformation. In summary, the results showed that the durability of the pavements – AC, RUBIT and Verglimit – is much the same in all three cases. However, RUBIT is a stone rich asphalt mix, similar to stone mastix asphalt, and from other studies and experience one would expect this type of asphalt to have less pavement wear than an ordinary asphalt.

The primary purpose of the test stretches was to ascertain the skid proneness of the pavements. As a summary the studies of RUBIT and Verglimit were not able to show that these types of pavement have a marked skid-preventive effect during winter conditions on a high volume road with high winter maintenance standard. As in earlier studies on test stretches of this kind, the results varied widely.

It was found that on some occasions, particularly at temperatures around 0°C and with hoarfrost, Verglimit and RUBIT had an effect, skid resistance was better on the test sections than on adjacent conventional pavements. In figure 6 skid resistance in such a situation can be seen. Early this december morning hoarfrost had formed due to cold and clear weather. The formation was most intense on the asphalt concrete pavement and to some extent on the rubber asphalt. The section with Verglimit had very little hoarfrost which also showed in a better skid resistance than the compared surfaces. This better skid resistance remained until ½ an hour after the salting measure.

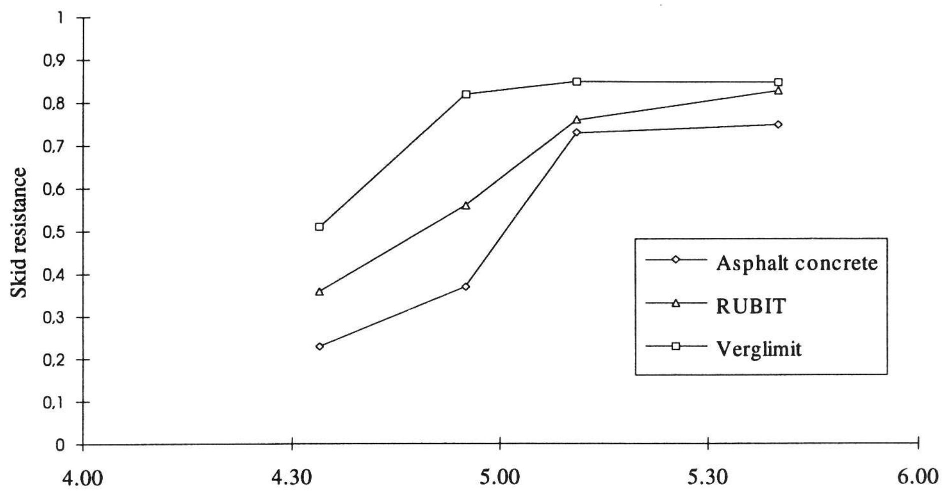

Figure 6. Skid resistance on asphalt concrete, RUBIT and Verglimit in a situation with hoarfrost. Salt spread at 4.30 a.m.

However, occasions such this, with a good skid-resisting effect, were relatively rare during a winter. The benefits to be gained from using these types of pavement on roads with a higher traffic density and a good standard of winter road maintenance therefore remain doubtful.

Conclusions

The studies reported in this paper have shown:

- a coarse texture is in many cases favourable from the point of view of skid resistance in wintertime. This was most obvious on newly-laid surface dressings in particular. However, the favourable skid resistance effect in winter as compared with smooth asphalt concrete diminished as the texture wore down and became smoother.
- porous asphalt pavements are generally somewhat less skid-resistant and require more extensive de-icing measures than conventional dense asphalt concrete. To minimize the use of salt preventive spreading is often performed prior to snow fall and ice formation. Due to its self draining effect porous asphalt sometimes has to be treated more frequently and with higher application rates.
- Verglimit and RUBIT have shown to have a skid-preventive effect on some occasions, particularly at temperatures around 0°C and with hoarfrost/ice formation. However, these situations were relatively few and the benefits to be gained from using these types of pavement on roads with a higher traffic density and a good standard of winter road maintenance therefore remain doubtful.

METHODS AND STRATEGIES TO ACHIEVE A CHOSEN WINTER ROAD STANDARD

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ABSTRACT

The harm caused by salt can be reduced by using methods and materials, both chemical and mechanical, which more effectively counteract existing or probable slippery conditions. More effective use of salt, new de-icing methods and agents have been tested in the 1985–1990 Swedish MINSALT-project with the aim of finding more effective ways of improving skid resistance which do not have the negative effects of salt.

Salt-spreading methods have progressed form earlier dry salting to the spreading of prewetted salt and brine. The results from the MINSALT-project have led to a proposed strategy that will reduce the salt consumption and make the salting more effective. This can be accomplished by working more with anti-icing measures, before the icy conditions occur, and less with de-icing. Prewetted salt or brine should be used.

Les effets nocifs du sel peuvent être réduits en utilisant des méthodes et des produits chimiques et mécaniques agissant plus efficacement contre des conditions de dérapage existantes ou probables. Une utilisation plus efficace du sel, de nouvelles méthodes et fondants routiers ont été testés de 1985 à 1990, dans le cadre du projet suédois MINSALT, qui avait pour objectif de trouver des moyens plus efficaces d'améliorer la résistance au dérapage tout en évitant les effets négatifs du sel.

Les méthodes d'épandage du sel ont progressé depuis l'épandage de sel sec d'autrefois à l'épandage du sel humide et de la saumure. Les résultats du projet MINSALT ont abouti à la proposition d'une stratégie permettant de réduire l'utilisation du sel et de rendre l'épandage plus efficace. Ceci peut être réalisé en travaillant davantage avec des measures anti-verglas avant même l'arrivée des conditions de verglas, et moins avec des mesures de dégivrage. Du sel humide ou de la saumure devraient être utilisés.

Die von der Salzstreuung verursachten Schäden können durch den Einsatz von sowohl chemischen als auch mechanischen Methoden und Materialien, welche eine bessere Wirkungskraft gegen bestehende und voraussichtliche Glätte haben, verringert werden. Im Zuge des im Zeitraum 1985-1990 durchgeführten schwedischen MINSALT-Porjekts wurden ein effektiverer Einsatz der Salzstreuung, neue Enteisungsmethoden und Wirkstoffe getestet, um effektivere Methoden zur Verbesserung der Griffigkeit zu finden, welche nicht die negativen Auswirkungen der Saltzstreuung haben.

Die Methoden der Salzstreuung haben sich von der früheren Trockenstreuung zur Streuung vorbefeuchteten Salzes und der Verwendung von Salzsole hin entwickelt. Die Ergebnisse des MINSALT-Projekts zogen die Empfehlung einer Strategie nach sich, durch die sich der Salzverbrauch verringern und die Salzstreuung effektiver gestalten wird. Dies läßt sich dadurch erreichen, daß Anti-Eismaßnahmen bereits gesetzt werden, noch bevor Straßenglätte auftritt, und daß Enteisungsmaßnahmen in geringerem Maß eingesetzt werden. Die Verwendung von vorbefeuchtetem Salz oder Salzole wird empfohlen.

Introduction

The harm caused by salt can be reduced by using methods and materials, both chemical and mechanical, which more effectively counteract existing or probable slippery conditions. More effective use of salt, new de-icing methods and agents have been tested in different projects in the 5-year study of the Swedish MINSALT programme. Projects conducted during 1985–1990 with the aim of finding more effective ways of improving skid resistance which do not have the negative effects of salt. The results from the MINSALT projects have been reported in different reports and summarized in final reports in Swedish and English (1).

In regard to chemical de-icing – i.e. salting – spreading methods have progressed from earlier dry salting to the spreading of prewetted salt and saline solutions. Experiments aimed at using NaCl more efficiently included studies of optimum spreading rates under different weather and road surface conditions. The importance of the road structure, the wearing course and the salt (origins and gradations) were studied. A number of different chemical alternatives to NaCl have also been tested. In particular, calcium magnesium acetate (CMA) has been studied more closely in regard to its ice-melting capacity, corrosiveness and effect on concrete.

As a rule, de-icing by spreading sand on the roads also entails spreading salt because the sand used for this normally contains about 3 % by weight of salt, to permit its storage in cold weather, to facilitate spreading and to make it more effective on an ice and snow cover. Several possible salt-free alternatives such as lime stone products and chippings have therefore been tried out within the scope of the project. Finally, more efficient methods of ice scraping and snow ploughing have also been tested. By reducing any remaining layer of ice and snow, the salt dosage needed to achieve an acceptable standard can be minimized.

Pre-wetted salt

Up to the mid 1980's, the spreading of dry salt was the only chemical de-icing method in Sweden. Under many conditions, the spreading of dry salt had limited effect and particularly when spread on dry roads as an anti-icing measure. Studies have shown that a large proportion of the dry salt ends up at the side of the road during the actual spreading process and that even more is blown off the road by passing traffic. A method to make the salting more effective is to pre-wet the salt before spreading. By prewetting the salt sufficiently before it is spread on the road, the time required for the salt to dissolve is reduced and the salt adheres better to the road surface.

The spreading of prewetted salt or a saline solution are methods which have been used for many years and they are now well-known techniques. The salt can be prewetted either when loading it onto the spreading vehicle or when spreading it. Water, NaCl or $CaCl_2$ solutions or other suitable solution can be used for prewetting the salt. Water and NaCl solution have been used in Sweden. $CaCl_2$ solution has been tested but not been used in Sweden on account of its aggressive effect on cement concrete, higher cost and the fact that no difference in its effect on ice and snow could be subjectively discerned in comparative tests with NaCl.

Special spreaders for prewetted salt were developed and put into road maintenance service during the 1980's. In addition to the hopper for the dry salt, these spreaders have a solution tank (capacity approx. 2 m^3), pump, spray nozzle and electrical equipment for regulating the amount of solution.

As it is discharged onto the spreader disc or passes through the discharge pipe, the dry salt is sprayed with brine.

A saturated (appr. 23 % by weight concentration) NaCl solution is used for prewetting the salt and for spreading saline solutions. Two types of saline solution plants are currently in use for the preparation of the saturated saline solution. One is based on filling a tank with salt and water which is pumped round until a saturated saline solution is obtained. Production volume is 8 m^3 of solution a time. The same container is used for manufacture and storage.

The other type of plant is based on forcing water under pressure through a bed of salt in a large tank. The saturated solution is then allowed to flow over to a 10 m^3 large storage receptacle. Manufacture of the saline solution is a continuous process and the amount of salt and water is metered automatically.

When spreading, as a rule, 30 % by weight of the saturated NaCl solution is added to the dry salt. The rate of dry salt is similarly reduced by 30 % at the same time. This means that the amount of salt spread on the road is automatically reduced. The reduction in the salt dosage is slightly more than 20 %. Over and above this automatic reduction, the higher efficiency of the method as compared with conventional spreading means that the amount of salt spread on the road can be further reduced.

The advantages of using prewetted salt instead of dry salt, as shown by the tests carried out with wet salt spreaders and the results of subsequent practical winter road maintenance applications, include:

- The salt is spread more uniformly with less wastage at the roadside.
- The salt adheres to the road surface better.
- Prewetted salt has a faster and more durable effect.
- Prewetted salt can be used at lower temperatures.
- Spreading speed can be increased.
- In some cases the road surface dries out quicker.

Summarizing, the advantages of prewetted salt mean that a smaller amount can be spread to maintain a certain standard and that preventive measures are possible with good result.

Simple prewetting with water.

Dry salt can also be prewetted in a simpler manner by spraying a saline solution or just water over it as it is loaded onto the spreading vehicle. The advantages of this prewetting method are that conventional spreaders can be used and that little capital therefore need to be invested in special new equipment.

In Sweden, the simpler prewetting technique was tested during the winter of 1987-88. Prewetting was accomplished by spraying water into the loaded salt hopper with a hose. Depending on the method of loading, the solution is added either by spraying it over the loaded salt from above or during the actual loading process if this utilizes a conveyor belt.

In the winter of 1988/89, tests with the simple prewetting method were carried out on a larger scale in about 70 local road maintenance areas. Besides some special studies practical experience of the method as used by road maintenance crews has been gathered through questionnaires and the results are summarized as follows:

- The proportion of water ought to be 80-100 litres per tonne in the light of special tests.
- It must be possible to measure the amount of water because equipment malfunctions if insufficient water is used.
- The method were tested at temperatures down to -12°C, but is generally used down to -6°C.
- Spreading speed has been 50-60 km/h.
- As a rule, 2-3 tonnes of salt has been prewetted, although tests have been carried out with up to 8 tonnes. The amount of salt which can be prewetted depends to some extent on the size of the spreader.
- Most of the road maintenance areas (about 90 %) have reported that the method produces good results and that they intend to continue using it.

Simple prewetting with water makes it possible to:

- Gain the advantages of prewetted salt with conventional spreaders at an extremely low investment cost.
- Improve the adhesion of the salt so that it stays longer on the road.
- Increase spreading speed.

One limitation of the method is that the spreader should not be loaded with more than 2-3 m³ of salt to ensure that it is thoroughly prewetted before spreading. However, this is enough for about 60-90 km of preventive salting. The limitations of the method make it better suited to road maintenance areas with lower traffic densities on their salted roads. In areas with more trafficked roads, on the other hand, prewetted-salt or saline-solution spreaders are more suitable for chemical de-icing and anti-icing measures.

Spreading of saline solution

De-icing with a saline solution entails spreading a saturated salt solution containing about 20-25 % by weight of NaCl. Spreading this solution on the roads therefore corresponds to only about ¼ of the amount of dry salt.

Swedish studies of spreading of brine were begun on a small scale in the winter of 1987/88. This smaller preliminary study consisted of a visual examination to assess spreading efficiency, the spreading pattern, the effect on the road surface, and refreezing, if any. Tests with spreading of brine were conducted on a larger scale in the following winters – 1988/89 in 7 areas and 1989/90 in some 20 additional areas.

Two types of spreading equipment for saline solution were tested, both speed-independent, which means that the amount spread is not dependent on the speed of the vehicle. The normal capacity of the tank of brine is 8 m³. The brine is spread on the road either by means of nozzles on a spreader arm or by means of two rotating discs. Depending on the spreader the width can be set between appr. 2 and 10 m and the application rate between 3 and 18 g/m² of dry salt. The dosage corresponds to appr. 10 to 80 g/m² of brine. The standard application rate for anti-icing measures and for removing thin layers of hoarfrost/ice was 20 g/m², corresponding to appr. 5 g/m² of dry salt. Additional spreader units were acquired by the National Road Administration for the 1989/90 season and the total number of spreader units in use was about 80. In the same way as in the previous winter, the spreading of saline solution was followed up with a questionnaire concerning the methods and spreading equipment used. The 26 local road maintenance areas and two municipalities covered by the study gave their views and reported on the results they had obtained.

Summarizing, experience gained during the three winters shows that:

- The method is considered to be extremely effective as a preventive measure and for dealing with hoarfrost on the roads.
- During a snowfall, the method is of doubtful merit. On wetter roads and where ice has already formed, the method is similarly of doubtful merit or downright unsuitable. Correct dosage is a critical factor. Dilution of the brine resulting in re-freezing can be a problem.
- A saline solution of 20 g/m² (corresponding to about 5 g/m² of dry salt) is sufficient in the majority of cases as anti-icing and less severe de-icing measures.
- The method has been tested on roads and motorways with ADTs ranging from 1,500 to 12,000 vehicles per day.
- Spreading has been possible at speeds of up to 60 km/h.

A new winter road maintenance strategy

The result of the MINSALT project was a proposal for a new winter road maintenance strategy which, in the light of the results of research and the experience gained from the project, showed how winter road maintenance can be organized so that its objectives can be attained. By adopting this proposed strategy, it was estimated that a reduction of salt consumption by about 20-40 % compared with what it was before the MINSALT project could be expected.

The overall objective of road maintenance is to help maintain the country´s total resources at a high level of efficiency. This objective can be broken down into the following road maintenance aims:

- A high standard of traffic safety
- Good trafficability and a high degree of availability
- Low vehicle costs
- A good environment

In rural areas these aims can be achieved by meeting the following standard requirements (described in functional terms) of roads in the winter.

Functional goals	**National roads**	**Regional roads**	**Local roads**
Uniform standard of trafficability	X	X	X
Dry road, free from snow and ice	X	X	
Even surface, free from loose snow			X

As far as is practicable, the following requirements apply to national and regional roads:

- If there is a danger of slippery road conditions, anti-skid measures should be taken to prevent the occurence of such conditions.
- De-icing and anti-skid measures should be carried out before peak traffic periods, and the time for these measures on national and regional roads respectively should be 1 and 2 hours.
- Snow deeper than 3 cm should not be allowed to remain on the road.
- The road should be free from snow not more than 2-3 hours after the snow has stopped falling. Strings of slush should not be left on the road.
- Snow should be cleared away from the verges when the roadway is free from snow.

Adoption of the following measures, methods and resources is proposed. It is important to use the right method at the right time.

- Where chemical de-icing is concerned, the method used should be the one with the lowest salt consumption.
- In the case of preventive salting, the salt should always be prewetted with 80-100 litres of water per tonne of salt if equipment for spreading a saline solution or prewetting salt with a saline solution is not available.
- Prewetted salt should not be spread wider than 4 m, regardless of the road width. The application rate compensates for the actual width to be de-iced.
- Salting in conjunction with snow ploughing should only be carried out when there is a danger of compaction or freezing.
- In the case of combined salting and snowploughing the salt should be spread only on the width of road that has been cleared of snow.

- Chemical de-icing should normally not be done on local roads. If possible, salt free abrasives like crushed stone aggregate should be used.

- The lowest temperture for chemical de-icing should be
  - 12°C on national roads
  - 8°C on regional roads
  - 3°C on local roads

- At lower temperatures than the above, the gritting material with the best adhesion, having regard to durability and availability, should be chosen.

- Sand mixed with salt should not be used when it is possible to use crushed limestone, natural sand or crushed stone aggregate.

- Snow-clearing equipment, incl. blade material, should be adapted to the prevailing snow and temperature conditions.

- Snow should be cleared from the roads as quickly as possible. If possible, salting should be delayed until the snow has stopped falling.

Further studies to optimize winter maintenance operations

The Operating rules of the National Road Administration specify standard requirements and quality level for winter road maintenance. The quality level is described by the requirements on road conditions and the timeframes available for achieving these conditions. The Operating rules do not state which method or strategy is to be used for achieving the chosen quality level.

A new project, that started in the winter 1992/93, aims at determining optimal measures for achieving the quality level described in the rules at the lowest community cost. To a certain extent, it is also necessary to review the chosen quality level in regard, for example, to differences between the carriageway and hard shoulders. The goal of the study is to have recommendations for strategy/action/working method in different weather and road conditions.

The investigation is made by field studies and analysis of the different weather and road conditions that have been present. Winter maintenance measures in a district, Gothenburg on the Swedish west coast, is followed very closely. Different measures are documented and the resulting road conditions are recorded. The result on the road is described primarily by skid resistance mesurements, video recordings and visual observations. The follow-up comprises 9 test sections,on appr. 60 km of roads of varying type (from 4-lane motorway to 7-m local road), traffic volume, standard requirements, deicing methods etc.

Skid resistance is monitored with a SAAB Friction Tester and recordings are made before the deicing or anti-icing measures and continues to bare pavement values is present. At the same time video recordings of the surface conditions on the different sections are made to give additional information to the analysis of the different situations. Visual observations are made and temperatures registered. Weather data is obtained from the Road Weather Information System of the National Road Administration. Of special importance is to have data on road surface temperatures and amount of precipitation. Type of maintenance measure, application rates, time of application etc on the studied roads are also registered.

Maintenance operations include the following snow removal and ice control techniques:

- Chemical deicing and anti-icing, salting - dry, pre-wetted with NaCl brine (special spreaders), pre-wetted with water, spreading of NaCl brine.
- Sanding.
- Ploughing - rubber or steel blades.

The follow-up is planned to cover at least two winters, until 1993/94, but the actual period will to some extent depend on if the number of situations followed during these two winters are considered to be enough for attaining the project goal. Icy conditions and counteracting measures will be shown with graphs of skid resistance and road condition (quality level) in different situations. After the investigation we hope to have an answer to questions like:

- What strategy and method is best suited on this type of road in this weather situation?
- What deicing method should be used in this situation?
- What application rate should be used?
- What is the temperature range for this method?

Conclusion

Salt-spreading methods have progressed from earlier dry salting to the spreading of prewetted salt and brine. The results from the MINSALT-project have led to a proposed strategy that will reduce the salt consumption and make the salting more effective. This can be accomplished by working more with anti-icing measures, before the icy conditions occur, and less with de-icing. Prewetted salt or brine should be used.

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Relation between Winter Road Maintenance and Road Safety

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ABSTRACT

The study was intended to determine how the accident risk varies during the hours before and after winter road maintenance has taken place.

Better knowledge of the effects on road safety of different action times and winter road maintenance methods is important for planning by road management authorities.

Cet exposé entend déterminer la façon dont le risque d'accident varie pendant les heures avant et après l'intervention de la viabilité hivernale.

Une meilleure connaissance des effets sur la sécurité routière de différents moments d'action et de différentes méthodes d'entretien des routes en hiver est importante pour la planification par les authorités des ponts et chaussées.

Zweck dieser Studie war es, zu bestimmen, inwieweit sich das Unfallrisiko in den Stunden vor und nach der Durchführung von Winterdienstarbeiten verändert.

Eine bessere Kenntnis der Auswirkungen der unterschiedlichen Zeitdauer der Maßnahmen und der Winterdienstarbeiten auf die Straßensicherheit ist für die Planung der Straßenverwaltungsbehörden wichtig.

Purpose and method

If a road management authority is to be able to optimize its resources for winter road maintenance also from a socioeconomics perspective, knowledge of the influence on road safety of action type and action time is required.

Earlier studies have shown that the accident risk increases rapidly with relatively small quantities of snow. However, knowledge of the duration of an increased accident risk and the level of the increase has been not been fully adequate.

In the study now completed, the accident rate has been calculated 12 hours before and 12 hours after an action. For the 12 hours closest to the action (6 hours before and 6 hours after), the risk has been calculated for each half-hour and for the remaining 12 hours, for each hour. The data obtained have made it possible to study the accident risk function for factors such as different maintenance types. Regional differences have also been charted, since in Sweden there are fairly large variations in climate and thereby road conditions during the winter period.

The analysis register built up has been based on the follow-up of winter road maintenances carried out by the National Road Administration. During several winters, a large number of operating areas have been linked to a PC-based system designed exclusively to follow up production in winter road maintenance. The system stores data on action type, location, starting time and completion time for the action.

Data from two winters, 1988/89 and 1989/90, have been used in the analysis and comprise 50 operating areas, divided into 25 in northern Sweden, 16 in central Sweden and 9 in southern Sweden.

The action data have subsequently been linked to the accident register in the National Road Administration's road database. On the road network forming the 50 operating areas in the register, 7,884 accidents reported by the police occurred during the two winter periods. When wildlife accidents and accidents at junctions are excluded, 941 accidents remained which occurred during the interval 12 hours before to 12 hours after the action.

Data on annual average daily traffic have also been obtained from the road database and have then been converted to hourly flows with the aid of indexes for year, month, day of the week and hour. The index values are based on large numbers of empirical measurements.

Results

The accident rate has been calculated for 12 hours before and 12 hours after the action respectively. Wildlife accidents and accidents at junctions have been excluded from the calculations.

Certain action types (various categories of salting) have been combined into a single class. The action types reported in the analyses are snowclearing, combined snowclearing and salting, salting (dry, pre-wetted and brine) and preventive salting. Sanding has been excluded from the analyses.

The accident rate is calculated as the number of accidents per million axle pair kilometres.

Figure 1 shows all actions for the whole of Sweden. The confidence interval (95%) in the diagram is based on the 941 accidents.

The diagram shows how the increases in accident rate during the hours before the action, reaching a maximum at 1 to 1.5 hours before the action is implemented. This maximum of 2.6 represents an increase by a factor of 12 compared with the mean accident rate calculated with the aid of the accidents occurring at least 12 hours before or after winter road maintenance action, i.e. for the complement to the time period shown in the diagram.

The accident rate is somewhat higher during the period 12 to 6 hours before an action, compared with 6 to 12 hours after the action. Part of the explanation may be that many actions are initiated early in the morning, which means that the "before period" comprises more hours of darkness than the "after period". Since the accident risk is higher in darkness than in daylight, this would explain the higher risk level before an action.

The fact that the accident rate is highest about one hour before the action may appear remarkable. However, the result agrees with the accident risks reported from similar studies in Germany and the U.S.A. The explanation may be that road users have begun to reduce their speed and adapt their driving behaviour to the poorer road conditions, with the result that the accident rate begins to decrease somewhat before the action is implemented. Earlier studies indicate that the accident rate decreases when slippery surfaces or poor road conditions occur frequently or for a long period of time.

Figure 2 shows the accident rate for isolated actions (i.e. when actions are implemented more than 12 hours before or after another action).

The accident rate function for the isolated actions has a similar appearance to the corresponding function for the entire material, with the difference that the maximum level is considerably higher. This supports the above theory that the accident rate is higher when slippery or poor road conditions occur rarely or for a short time.

When a division is made according to accident type, it is seen that the maximum accident rate in preventive salting is half as great as the corresponding rate for other measures.

Action type	Accident rate
Salting	3.4
Snowclearing with salting	3.4
Snowclearing	2.5
Preventive salting	1.6

In a division by accident type, the maximum value for single vehicle accidents is 3-4 times as high as the corresponding value for the other accident types.

As expected, the maximum accident rate for southern Sweden is considerably higher than the corresponding rate for other regions. The probable explanation is that the frequency of studded tyres is higher in northern Sweden, at the same time as slippery conditions and snow occur far more often and for longer periods in northern Sweden.

Region	Accident rate
Southern Sweden	5.0
Central Sweden	3.0
Northern Sweden	1.6

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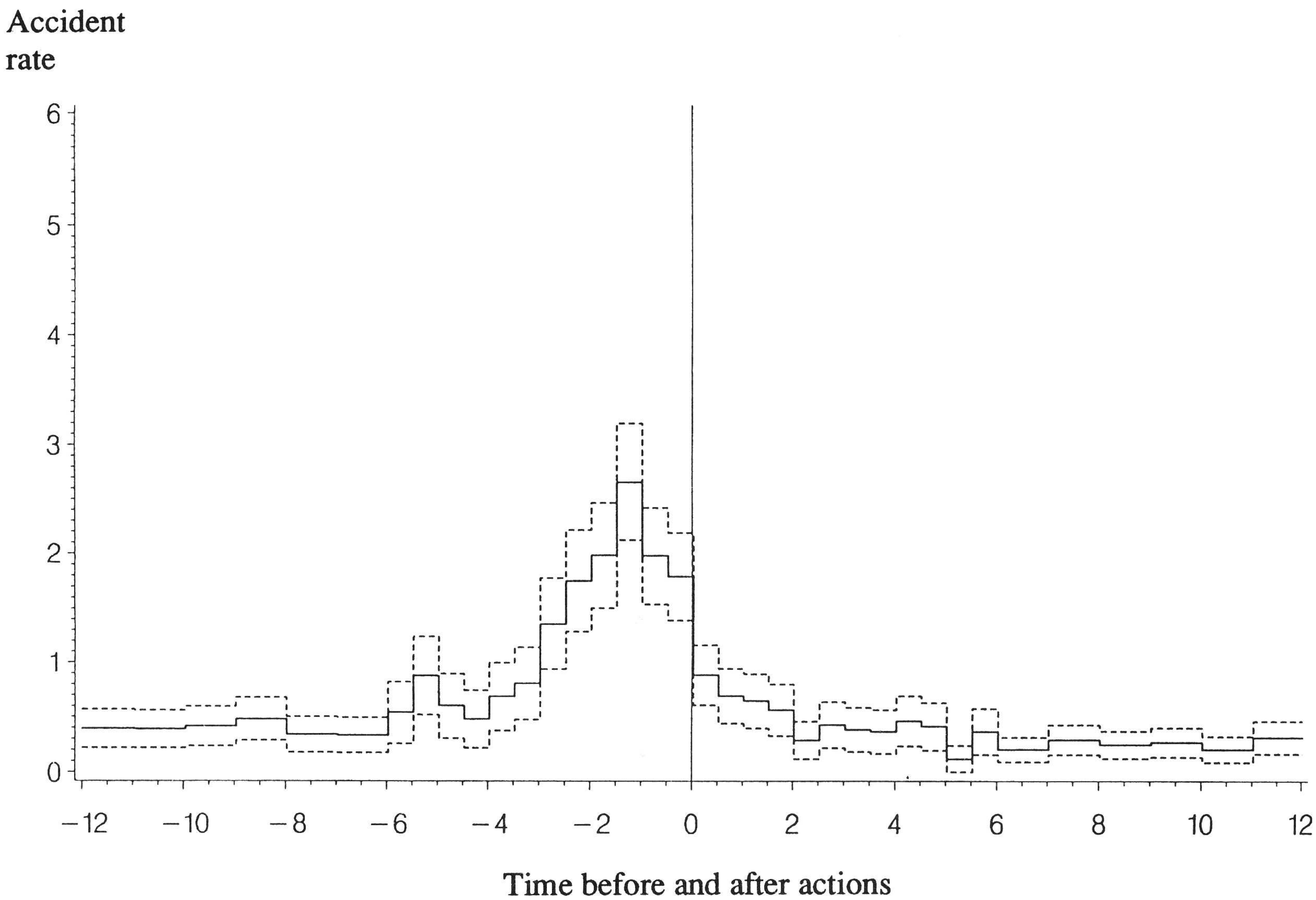

Figure 1. Accident rate for all actions for the whole of Sweden. The confidence interval (95%) is based on the accidents.

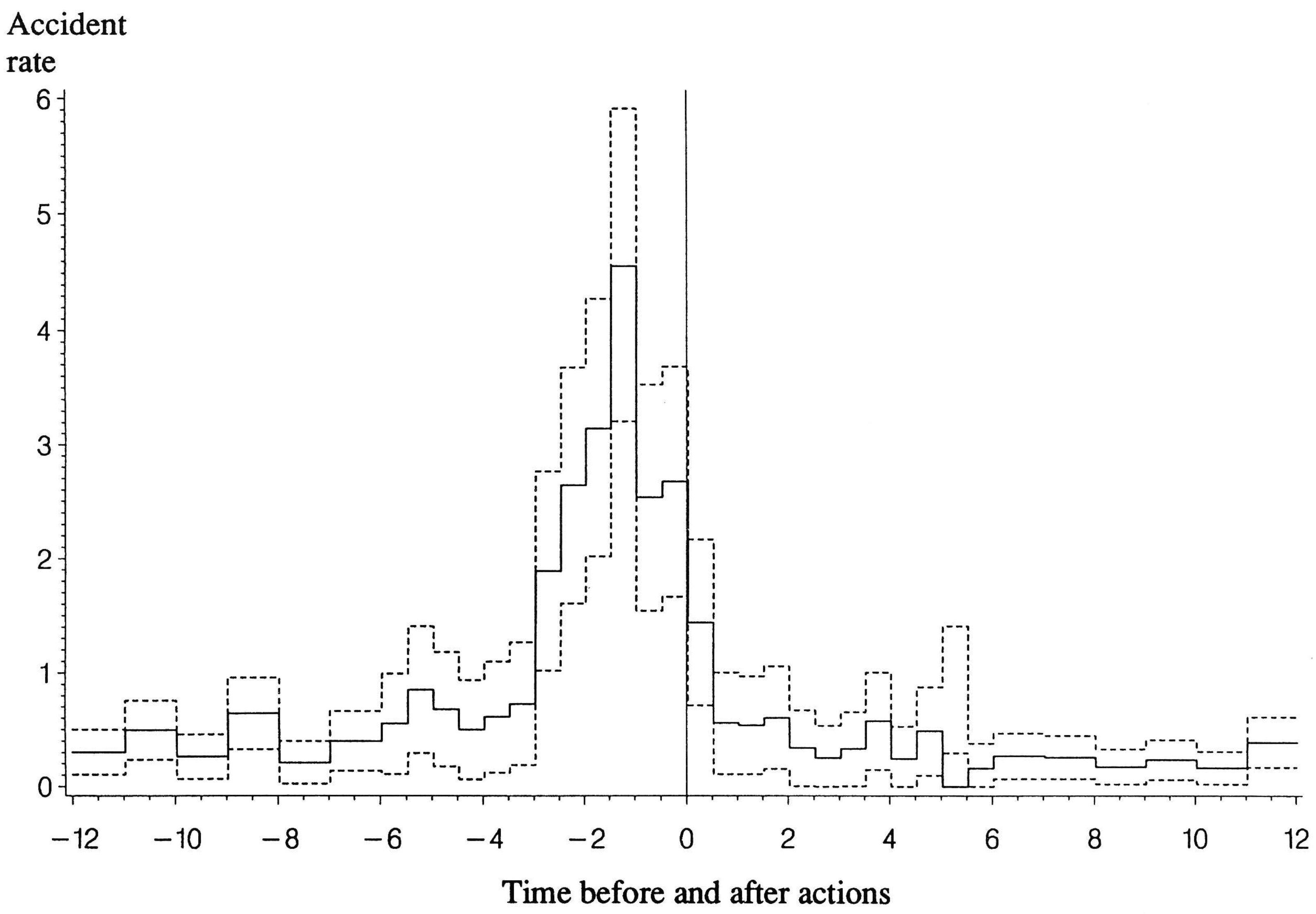

Figure 2. Accident rate for isolated actions (i.e. when actions are implemented more than 12 hours before or after another action.

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