Winter Road Maintenance Methods in Finland

Helsinki 1993

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ISBN 951-47-8115-5
TIEL 2230006E

Kangasalan Kirjapaino Oy
Kangasala 1993

The name of the original copy:
Teiden talvihoito II; Menetelmäohjeet

Published in Helsinki 1992
ISBN 951-47-6071-9
TIEL 2230006

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Introduction

Finland makes an exceptional challenge to a road authority. The geology varies from soft clays to hard rock, climate from hot summers to Arctic winters. The country is large and sparsely populated with tens of thousands of lakes and rivers. Society demands a high level of service, economically efficient road keeping methods and environmentally sustainable policies at the lowest possible cost. However, the Finnish road network is in excellent condition providing efficient and fast transport facilities for the society. As proof of this, highway transportation is the overwhelmingly dominating mode in both passenger and goods transport.

Finnish National Road Administration, FinnRA, is responsible for the challenging task of the management, planning and design, construction, and maintenance of public roads in Finland. In the difficult conditions we have been forced to continuously develop our operations and management to be more effective and cost-efficient year after year. The result is a professional and well-educated staff, modern management culture and a wide range of advanced highway management systems and technologies that are acknowledged worldwide - and used as models by other highway authorities.

FinnRA's expertise has been used abroad starting from the mid-1970's through FinnRA Export Services. It is a financially independent division of FinnRA providing consulting and training services for transport sector projects worldwide, using the resources and know-how of FinnRA, Finnish consultants, and other professional organizations.

This publication will present you winter road maintenance methods used in Finland. Hopefully it will also convey information about some Finnish know-how and technologies that you could benefit from. We would very much like to share our experiences with you.

Selected text for this publication was translated from the original Finnish copy by Tapio Raukola, FinnRA, R & D Unit in Tampere.

Finland

Finland is situated between the 60th and 70th degrees of latitude and it is the northernmost country in the world after Iceland. Finland is one of the Scandinavian countries and its neighbours are Sweden and Norway in the west, Russia in the east and Estonia in the south. On the south and west, Finland is bounded by the Baltic Sea.

Compared by area, Finland is among the largest countries in Europe. 10% of the total area of 338,000km^2 is water, 65% forest and 8% cultivated land. The population is 5 million, out of which 94% speak Finnish and 6% Swedish as their mother language.

Finland is a politically neutral western democracy with a President elected to a six-year term and a 200-member, single-chambered parliament elected every four years. Finland is a member of EFTA and is currently negotiating about membership in the EC. The GDP per capita in 1992 was some 22 000 USD, ranking the 15th highest in the world.

Finland is famous for its highly developed industrial companies, especially the forest, shipbuilding, chemical and electronics industries. Internationally well known products connected to winter roads are road weather information systems, tires and mobile telephones.

The January mean temperature in the south is about -5°C (23°F) and in the north about -15°C (5°F). The winter starts in October - November and lasts till March - April.

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1 OBJECTIVES

1.1 Winter Maintenance Standards

The Finnish National Road Administration (FinnRA) has established winter maintenance standards. These determine the level of service that is provided to each highway in Finland. The winter maintenance level of service is based on traffic volume, time of day, and removal operations (snow plowing, de-icing, and slush removal). For winter maintenance measures the highways are classified according to their functional class and traffic volume (ADT). The classification table is as follows:

Highway Winter Maintenance Classification

ADT	TRUNK ROADS	MAIN ROADS	REGIONAL ROADS	CONNECTING ROADS
> 12000	Isk	Isk	Isk	Is
6000 - 12000	Is	Is	Is	I
3000 - 6000	I	I	I / Ib	Ib
1500 - 3000	I	Ib	Ib	Ib
500 - 1500	Ib	II	II	II
200 - 500	II	II	II	III
< 200	II	II	III	III
Pedestrian and Bicycle paths	IV	IV	IV	IV

Bare Pavement Roads
Snow Surface Roads During Cold Winter Conditions
Snow Surface Roads

(See also table:
Target Condition Values and Cycle Time)

Note: Isk = super divided, Is = super undivided,
Ib = thin layer of packed snow allowed

Table 1: The highway maintenance classification.

The trunk road network is a system which holds together the regional structure of the country. Most trunk roads have two lanes, but the roads of highest traffic volume are freeways or semi-freeways (undivided with interchanges) or four-lane roads.

The main roads complete the trunk road network. The standard of the main roads is very near that of the trunk roads. Main roads are either two-lane or four-lane roads.

The regional roads connect local urban centers and other regionally important locations.

The connecting roads are those public roads which do not come in the higher road classes. Most of them are low traffic volume roads with a gravel surface.

All types of roads described above are maintained and constructed by the National Road Administration.

For each highway maintenance class FinnRA has a certain condition standard. When the road conditions fall short of this standard, it must be brought back up to the required level within a certain time period.
Slipperiness, snowiness and evenness are regarded as variables of the condition standards as follows:

	LEVEL OF SERVICE				
Quality class variable	1 Poor	2 Fair	3 Satisfactory	4 Good	5 Excellent
SLIPPERY CONDITION Skid number Road surface texture	0,00-015 Very icy driving or otherwise very slippery	0,15-0,25 Dry ice or snow packed	0,25-0,30 Coarse ice or snow packed in cold weather	0,30-0,45 Bare and wet or packed snow between traffic ruts	0,45-1,0 Bare and dry
SNOW CONDITION Dry frozen snow Thawing snow Slush Drifting snow	> 50 mm > 40 mm > 30 mm Easy passage may be difficult in some places, car may become stuck in a snowdrift	< = 50 mm < = 40 mm < = 30 mm Drifting over the road or moderate snow layer at the road edges, driving speed must sometimes be reduced	< = 30 mm < = 25 mm < = 20 mm Drifting here and there over the road, driving speed has to be reduced in some cases	< = 20 mm < = 15 mm < = 10 mm Drifting here and there to the middle of the outermost traffic lane, generally no need to reduce the driving speed	- - - -
EVENNESS Ruts Other roughness	< 30 mm Path very uneven, possible projecting bumps, driving speed must be reduced and uneven spots avoided	< = 30 mm Plenty of worn spots or disturbing holes, driving speed must be reduced in some places	< = 20 mm Path even, possible unevenness does not actually disturb driving	< = 10 mm Thickness of path strips on the road portion under traffic < = 10 mm	- -

Table 2: Finland's quality standards for winter maintenance.

The cycle time is the length of time between a substandard road condition and its restoration. The range of target condition values and cycle times are as follows:

Target Condition Values and Cycle Time

HIGHWAY Class	TARGET Condition Value	CYCLE TIME De-icing	Snow Removal	Slush Removal	Leveling
Isk	4	2 h	2,5 h	2,0 h	1 day
Is	4	2 h	2,5 h	2,0 h	1 day
I	4	2 h	3,0 h	2,5 h	1 day
Ib	4/3	3 h	3,0 h	3,0 h	1 day
II	3	4 h	4,0 h	4,0 h	3 days
III	2	6 h	6,0 h	6,0 h	5 days
IV	3	4 h	4,0 h	4,0 h	2 days

Table 3: Target Condition Values and Cycle Time

The friction requirements apply when the temperature is not colder than described in the following table.

Application of Target Condition Values

Highway Class	Target Condition Values Apply	Salt used when warmer than °C/°F
Isk	24 h/day	-8 / 18
Is	24 h/day	-6 / 21
I	Always except for the silent night hours.	-6 / 21
Ib	24 h/day for the value 3. Value 4 always except for the silent night hours.	-2 / 28
II	On weekdays: from 6.00 to 22.00 hours. During weekends: only daytime.	-
III	On weekdays: from 6.00 to 22.00 hours. During weekends: only daytime. During other times value 2 applies to slipperiness. The allowed maximum snow depth is 10 cm.	-
IV	Same condition value applies as on adjacent roadway.	

Table 4: Conditions where the required friction values apply.

Further instructions can be given by the Central Administration for each year and specific purposes.

2 WINTER OPERATION PLAN AND PREPARATIONS

2.1 Principles

Efficient implementation of winter activities requires a plan for use of personnel, equipment and materials. Equipment must be checked and calibrated. The winter roads must be planned and marked on a map.

The plan should include alternatives for equipment break-downs and changing weather conditions. A personnel plan includes an agreement for the hours of overtime and responsibilities for each person.

2.2 Snow Removal Plan

A snow removal plan based upon the winter maintenance standards, needs to be developed. It is possible to use computers to find the optimum routes for each snow removal unit.

In order to save money, cooperation between FinnRA and cities/ municipalities is recommended. Responsibilities at each change of jurisdiction, need to be worked out.

2.3 Leveling Plan

Motor graders are used to remove packed snow on high volume roadways. On other highways plowing units with underbody blades are used to remove loose and packed snow. Many types of cutting edges can be selected for different snow and ice packed conditions. The pivot type rolling cutter (System 2000) is very effective in removing packed snow.

2.4 Ice Control Plan

Efficient management of ice control is the most demanding and critical winter maintenance activity. The operations must be timely, salt must not be wasted, and the results must be good. The work can be either proactive or reactive depending upon the roadway classification. Salting activities are both an art and a science with good planning being half of the effort.

2.5 Snow Stake Plan

Snow stakes are used for identifying the edge of the roadway. During heavy snows they help the driver to stay on the road. It is necessary to place the snow stakes before the ground freezes. The distance between each stake depends on the geometry and the width of the road. Reflective stakes are recommended for high volume roads.

Geometry	**Distance of Stakes (m)**		
Width:	**<7 m**	**7-9 m**	**>9 m**
Straight	80	90	90
Moderate Curves	60	80	80
Winding Roads	40	50	70

Table 5: Distance between the snow stakes.

The length of each stake varies from 1.5 to 2.0 m.

Picture 1: An automatic snow staking unit mounted on a truck.

Picture 2: A snow stake setting device mounted on a light truck.

3 SNOW REMOVAL EQUIPMENT

3.1 Basic Units

The basic snow removal fleet consists of the following vehicles:

* **Trucks** for all kinds of snow removal activities
* **Light weight trucks** for the pedestrian and bicycle paths and for some secondary roads
* **Pick-ups** for minor amounts of snow
* **Tractors** for various countermeasures
* **Motor graders** for wet-snow removal on main highways and in townships and for lowering snow embankments on all highways
* **Wheel loaders** for loading and removing snow.

The maintenance of this equipment is completed as soon as the situation allows. This prevents delays or shortages in equipment for the next occurrence.

3.2 Basic Unit Accessories

3.2.1 Snow Plows

There are many varieties of plows including: one-way front plows, V-plows, double-blade plows, extendable plows, reversible plows, underbody plows, side wings and plows specifically designed for slush removal (flexible in ruts). All of the plows are hydraulically controlled. It takes only minutes to mount and unmount the plows using the quick-change buffer system. The straight steel cutting edges are the most commonly used. However, the wear resistant blades have started to become more and more popular.

The one-way front plow is the most common in Finland. It is the basis for further development of other plows such as the double-blade and extendable plows.

Picture 3: A one-way front plow. The operational width is about 2.8 to 3.0 m.

V-plows are used only for very deep and heavy layers of snow or when a road is blocked.

Picture 4: A modern V-plow.

Reversible plows are useful on freeways, because snow can be removed to either side of the highway. The most modern types are of double blade construction.

Picture 5: A reversible plow. The operational width varies from 3 to 4 m.

Hydraulically extendable plows have recently been developed. The width of the plow can be extended on the left or right hand side depending on the manufacture. They suit best to roads which vary in width (like many of the gravel roads in Finland). The extendable plow allows width adjustment between 2.8 and 3.5 m.

Picture 6: A left hand extendable plow (driver's view).

Picture 7: A right hand extendable plow (driver's view).

Double-blade plows have the main cutting edge made of steel and the secondary blade of rubber compounds for slush removal.

Picture 8: A double blade plow. The plowing width is from 2.8 to 3.0 m.

Slush removal plows consist of one or more cutting edges. The slush blades are spring loaded or hydraulically controlled to maintain pressure on the roadway surface. These plows are more flexible for cleaning ruts. The ruts are a result of studded tire usage in Finland.

These plows can not remove wet or packed snow, because the rubber edges are not capable of withstanding the pressure. On smooth highways steel cutting edges are good for slush removal.

Side wing plows can be attached to trucks and motor graders. The one way front plow and the underbody plow can be used simultaneously with the side wing. The side wings are needed when the width of a roadway is more than 7 m.

The side wing is also used for lowering snowbanks in wintertime and for pushing the bank away from road surfaces in springtime.

Picture 9: A side wing used with a reversible plow.

3.2.2 Other Snow Removal Equipment

Motor graders can utilize a large variety of accessories as follows:

* Side wing plows
* Snow cast extensions and smaller main blade extensions to cast snow over the snow banks
* Side ditch cleaning wings for lowering snow banks
* Bulldozer blades to clean intersections etc.
* Snow blowers to cast the windrow over the snow bank
* Snowstop flanges to prevent windrows at intersections or driveways
* Blades for slush removal

Picture 10: A snow cast extension.

Picture 11: A snowstop flange.

Picture 12: A motor grader side wing.

Picture 13: Excavators with a proper blade can be used to lower snow banks.

Snow blowers are used only in special situations for snow removal in Finland.

Tractors with plows or sometimes tractors and trucks with a broom are used for snow removal on pedestrian and bicycle paths.

Snow scoops are large scoops capable of shovelling snow efficiently. They are sometimes furnished with three-dimensional unloading facilities for urban areas.

4 PLOWING SAFETY FACTORS

4.1 General

There are plenty of dangerous situations in plowing work. Plowing itself can endanger people and property. For instance, side wings must be handled with care to avoid obstacles and pedestrians. A work training program is necessary to adequately teach skills for safe plowing.

4.2 Plowing Speed

A safe plowing speed can range from 40 to 60 km/h (25-35 mph). It is possible to plow at 70 km/h (45 mph), but results in poor quality. Drivers must always remember to slow down according to conditions on and near the highway. Sometimes snow clouds cover plowing units and limit the sight distance to a minimum. Using a low speed the cloud becomes smaller.

4.3 Plowing Units among People and Other Vehicles

Plowing units must stop or slow down at certain intervals, in order to give the other roadway users a chance to pass. It is always important to keep watch so that snow discharge does not hit people, vehicles or other property.

Picture 14: Snow clouds increase the risk of severe accidents.

4.4 Preventing Damage to Traffic Signs and Signals

During snow removal operations, the discharge snow can damage traffic signs and signals. The damage can be prevented by using a discharge direction control of the plow or by slowing down the plowing speed. Snow covered signs and signals must be cleaned as soon as possible.

4.5 Avoiding Overwidth Plowing

Overwidth plowing means plowing over the edge of the highway. This causes a danger for vehicles to swerve into ditches. If this occurs, location must be marked with new snow stakes immediately.

5 PLOWING METHODS

5.1 Alternative to be Used

The number of plowing units and the methods to be followed at each time, depend on cycle times, length of the route, width of the road and the consistency of the snow.

It is more and more common to use the plowing unit for simultaneous plowing and de-icing activities. In addition to the one-way or reversible plow, the unit can be equipped with a side wing and/or an underbody plow.

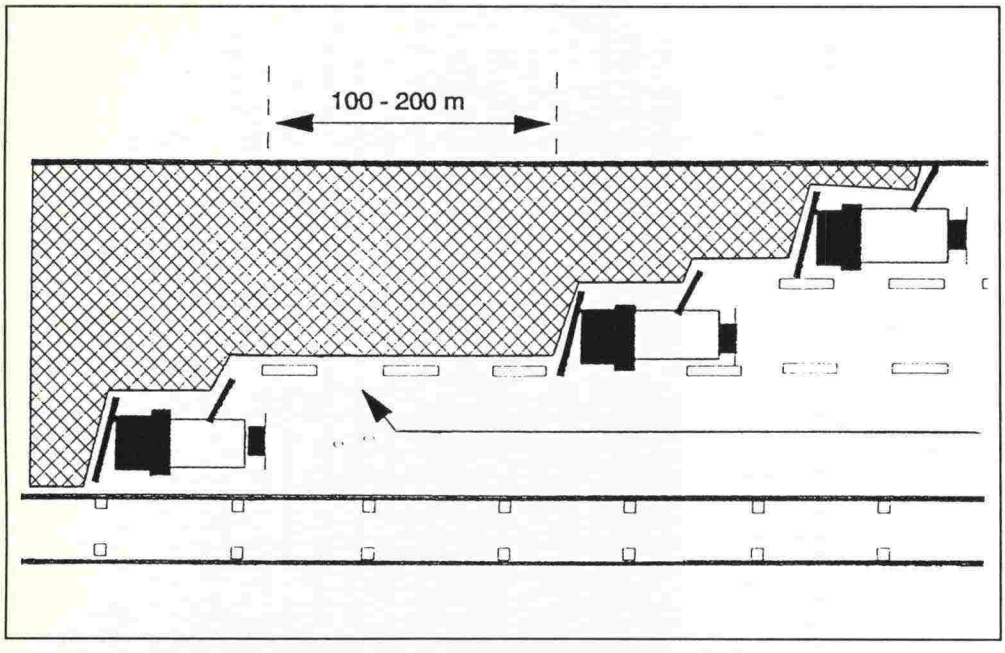
5.2 Undivided Highways

If only one-way front plows are used, two plowing units are needed. If the unit uses an extendable plow or has a side wing with a front plow, one unit has the operational width capability. If the plow is not wide enough, the traffic will move some of the snow back to the roadway or spreads it out. This is undesirable in the cleanup process. During snow storms, only the roadway is plowed. Afterwards, snow is removed from the shoulders and bus stops.

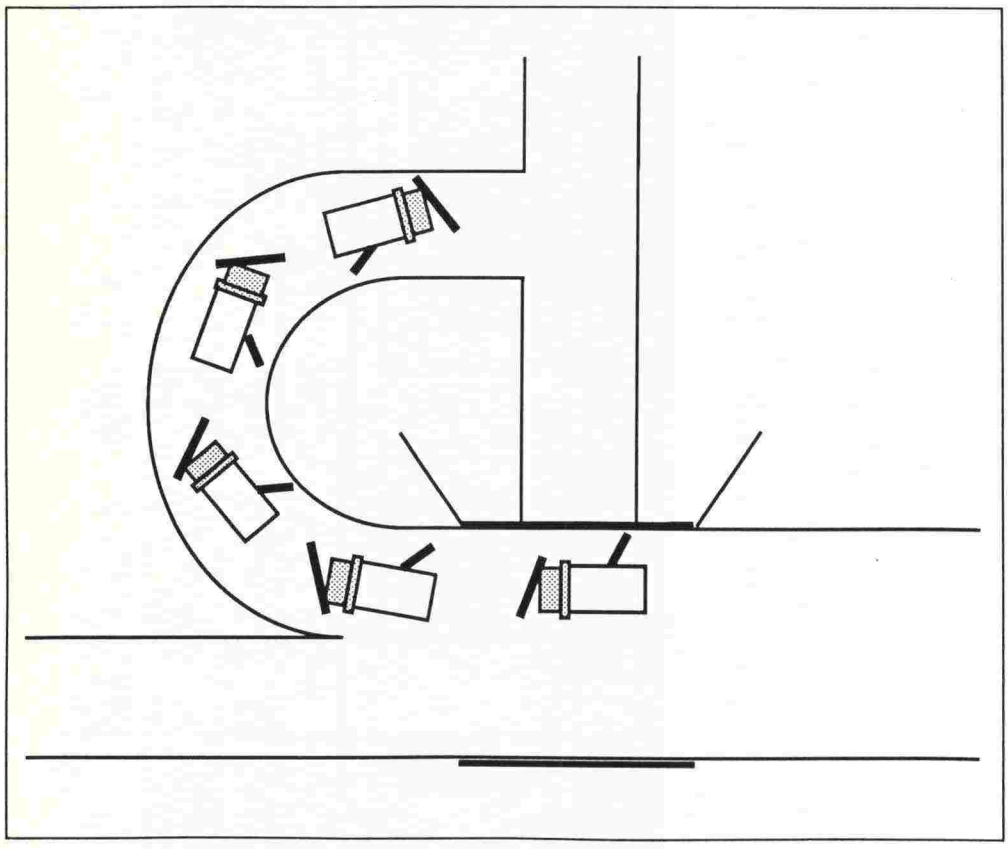
5.3 Divided Highways

On these highways 2-3 units are needed to achieve a clean roadway with one pass. Normally the work is carried out so that the first unit with a reversible plow is driving on the leftmost lane removing snow either to the left (if there is space available) or to the right. The second unit follows behind on the next lane using a side wing and to move snow to the right. The last and the rightmost unit removes snow from the roadway. During the operation the drivers must keep in touch to establish good distances between them and for letting other vehicles pass.

Plowing of ramps is time consuming. Usually one unit is needed to clean them. Reversible plows work best.



Picture 15: Plowing units on a divided highway.



Picture 16: A diagram of how to utilize a reversible plow and side wing to efficiently clean ramps in one pass.

5.4 Pedestrian and Bicycle Paths

If a pedestrian and bicycle path is away from the motor vehicle lanes, their plowing operations can be done independently. If they are adjacent to each other, the motor vehicle lanes are cleaned first and the paths as soon as possible. The pedestrian and bicycle paths are usually given a high priority to discourage people from moving onto the shoulder of the roadway.

Pedestrian and bicycle paths can be plowed using light trucks, tractors or pick-ups. One-way or reversible light weight plows are used. Snow on bridges is removed first to the corner where there is space for storage, then removed further with wheel loaders.

It is very important to use rough cutting edges on paths so that slippery walking stretches are not created.

Picture 17: Plowing of pedestrian and bicycle path. The plow has a rough cutting edge made of steel with holes punched in it.

5.5 Working in Urban Areas

Urban areas have specific characteristics that need to be taken into consideration during the winter. They include:

* Elevated sidewalks should be plowed at the same time as motor vehicle lanes or as soon as possible afterwards.
* Heavy traffic including parked vehicles interfers with plowing.
* Structures such as manholes, curbs etc. are hazards and the plow driver must learn their location and avoid them.
* Sometimes snow must be hauled to the snow dumping areas.
* Snow covered vegetation must not be damaged.
* Plowing operations are best completed before the busy morning traffic.

One-way, reversible and extendable plows on trucks are all good for work in urban areas. Motor graders are often used due to their versatile characteristics.

5.6 Snow Removal Specialities

5.6.1 Drifting

Drifting in general is not a large problem in Finland. Though, there are large open areas where preventive measures are taken. Light snow starts to drift at the windspeeds of 4-5 m/s. Drifted snow packs hard and when plowing through it, drivers must be careful not to go into the ditch. V-plows work best for these difficult situations.

Preventive measures include road reconstruction or use of snow fences. The fences can be permanent or temporary. The permanent fences can be natural tree landscaping or built structures. Temporary fences are expensive and, therefore, the use of them has decreased during the past two decades. In addition, the plowing units have become much more powerful so the need for fencing is less.

5.6.2 Rest and Parking Areas

Rest and parking areas are cleaned after snowstorms. Those that are faraway are plowed with the roadways. Many areas are closed or their parking areas are reduced for the winter based on usage.

5.6.3 Overpasses and Railroad Grade Crossings

It is not allowed to drop snow from overpasses of highways and railroads. Plowing speed must be reduced sufficiently so that snow remains on the bridge and does not present a hazard to vehicles underneath. Later snow must be removed from the bridge. On short bridges the plowing unit can do it immediately.

When removing snow from railroad overpasses where electric cables pass below, extreme caution must be exercised to avoid danger of an electric shock. Mechanical protection on these bridges must be in good condition.

At railroad crossings the snow plow driver must be in the right gear so that no shifting is needed on the crossing. If snow clumps are moved on to the rails, they must be cleaned.

5.6.4 Bus Stops, Passing Lanes and Other Wide Stretches

When two units are used, bus stops are plowed together with the highway. The side wing and the extendable plow help to plow them as wide as possible with one pass. If only one plowing unit is used, only the most important bus stops are plowed with the roadway.

The leftmost lane of intersections: Snow storage capacity on the intermediate zone of intersections is often minimal. Therefore snow must be removed to the slope immediately.

Passing lanes and other wide stretches: There are stretches of highways where there are two lanes to one direction and one in the other direction. The left hand lane of the two is called a passing lane. In wintertime it needs a higher degree of maintenance to be in a safe condition as compared to the right hand lane. Slush must be removed frequently from both lanes.

5.6.5 Slush Removal

Slushy road conditions are about ten times more dangerous for traffic than bare and dry conditions. It is extremely important to remove slush from the middle of the highway as soon as possible. Rutting of highways requires special demands for slush removal equipment. Best slush removers are double and rubber blade plows.

The double-blade plows are very useful when the consistency of slush varies from wet to dry. Rubber blades can remove only wet slush efficiently. The

wetter the slush, the thicker the rubber blade can be. Normal plows, motor grader blades, and underbody blades can be equipped with rubber cutting edges. The quality of rubber is very important. A wearing test with several rubber compounds was conducted in a laboratory during the winter of 1992-93 in Finland. Rubber from used tires appeared to be best. The thickness of rubber blades should be between 30 and 50 mm.

It is important to remove slush to the shoulder, so that the traffic does not throw slush back onto the roadway.

5.6.6 Lowering and Pushing Back Snowbanks

High snowbanks limit the visibility at intersections and interchanges. They also cause more severe drifting problems. If the banks are very high, it is difficult to throw snow over them when plowing.

The maximum allowed snowbank height is about 0.8 m depending on the geometry of the road and susceptibility of drifting. Snowbanks should be lowered to about 0.4-0.6 m. Such work must be done carefully, not to damage snow stakes and guide posts.

To lower snowbanks, trucks with side wings, motor graders with accessories, wheel loaders, tractors and excavators can be used. Traffic control must be set up for work where the visibility is poor or traffic is heavy.

In the springtime snowbanks must be pushed away from the road shoulder onto the slope. Melting snow draining onto the roadway can cause surprising wet and icy stretches of highway.

Special attention must be given to areas where melting snow ponds on highway before the banks have been pushed back. In that case drainage must be provided through the bank.

Picture 18: Visibility problem with a snowbank.

Picture 19: Lowering snowbank with a side wing.

Picture 20: Pushing snowbank to the shoulder using a motor grader blade.

5.6.7 Activities After Plowing

The supervisors must be informed by the drivers about all the defects observed on the roads during the plowing activities.

All pieces of equipment are checked after the plowing and repairs are done immediately.

Plows etc. are kept in the yard so that they do not freeze to the ground.

6 LEVELING AND REMOVAL OF PACKED SNOW AND ICE

6.1 Objectives

Packed snow forms a good white driving surface for low volume roads. When unevenness or ruts occur, the surface is releveled back to good shape. The leveling operations are also used to make packed snow thinner. If the surface becomes very unconfortable for driving or if it is melting, the packed snow or ice must be removed. By leveling the surface, the condition is restored to the best possible level of service. The plow leaves a groovy surface texture, when the tooth, punctured or rolling pivot type cutting edges are used. It gives better traction for vehicles. The groovy surface texture is also important on pedestrian paths to avoid dangerous walking conditions.

Hard snow or ice packs are leveled and removed using motor graders. For smooth roadways, the underbody plows of trucks can be used as well. The underbody blades of tractors can be used for pedestrian and bicycle paths.

6.2 Leveling Methods

Undivided highways: If the width of a highway is 7 m or less, it can be leveled with one two-way pass of a motor grader or a truck. Two units or double two-way passes are needed for wider highways.

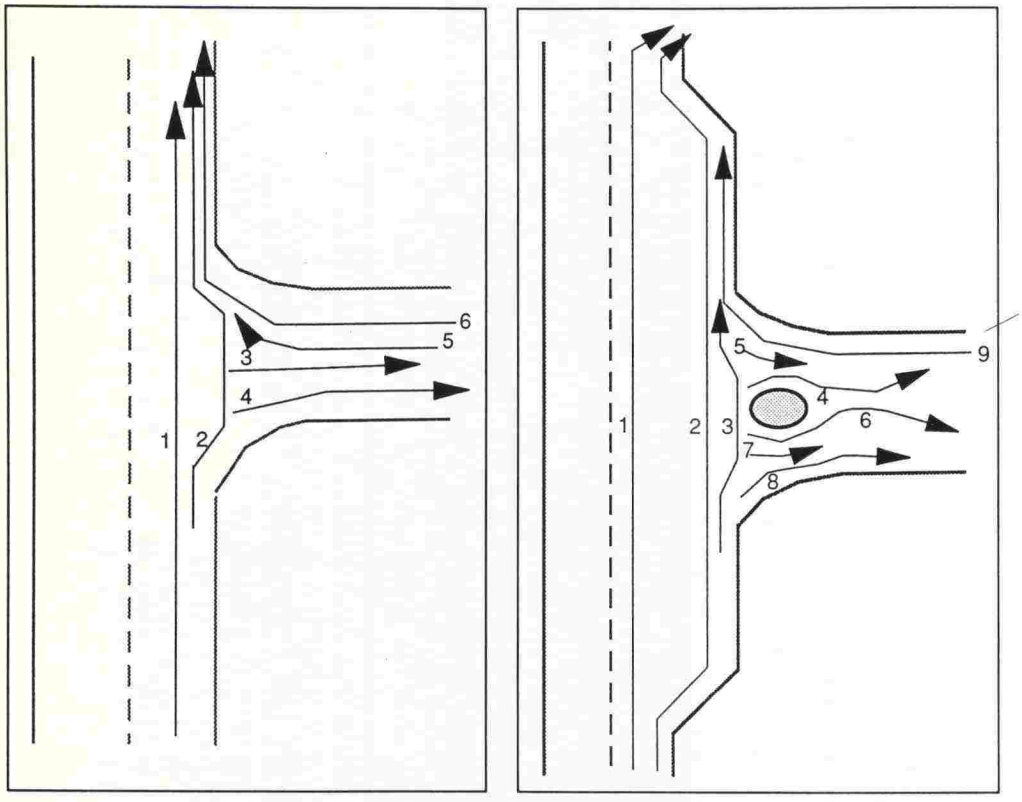
Multilane and divided highways: The method to be followed depends on the consistency of the packed snow/ice and the number of motor graders available for the job.

The snow is removed to either side of the highway if there is storage available. The windrows must be plowed away during the same day, otherwise they may freeze or harden. During plowing the distance between the work-units is kept to 200 m (about 200 yards).

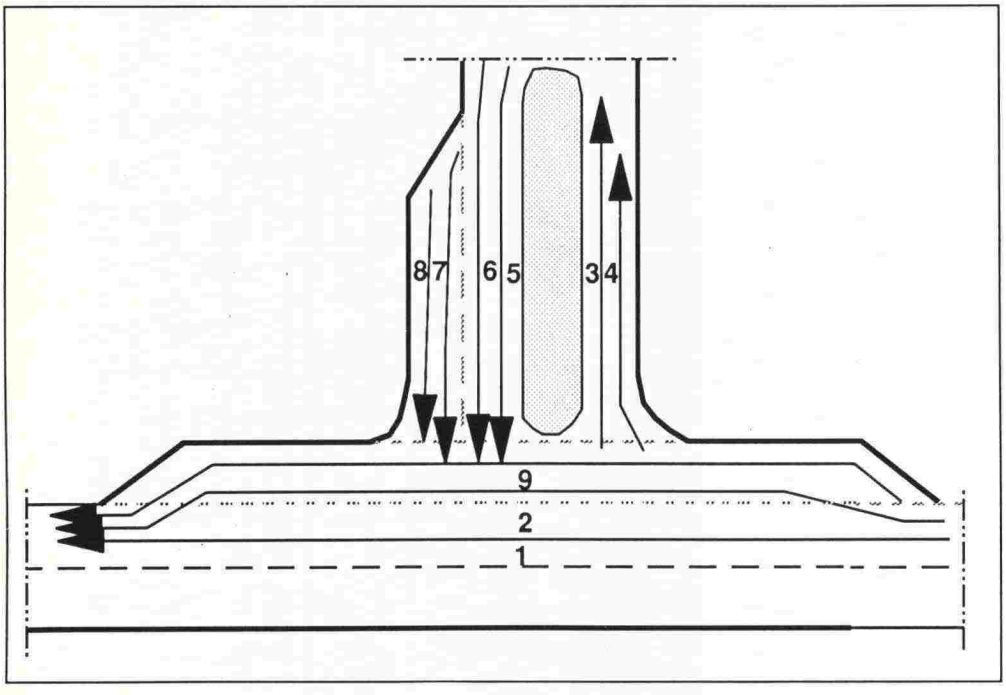
Bus stops, etc.: Bus stops and other pocket type widenings are leveled in connection with the main roadway. Large rest areas can be handled later, if the work delays main roadway operations too much.

Curves: At curves deep ruts often occur. Several passes are often needed to remove them.

Intersections: Intersections are leveled as shown in the pictures.



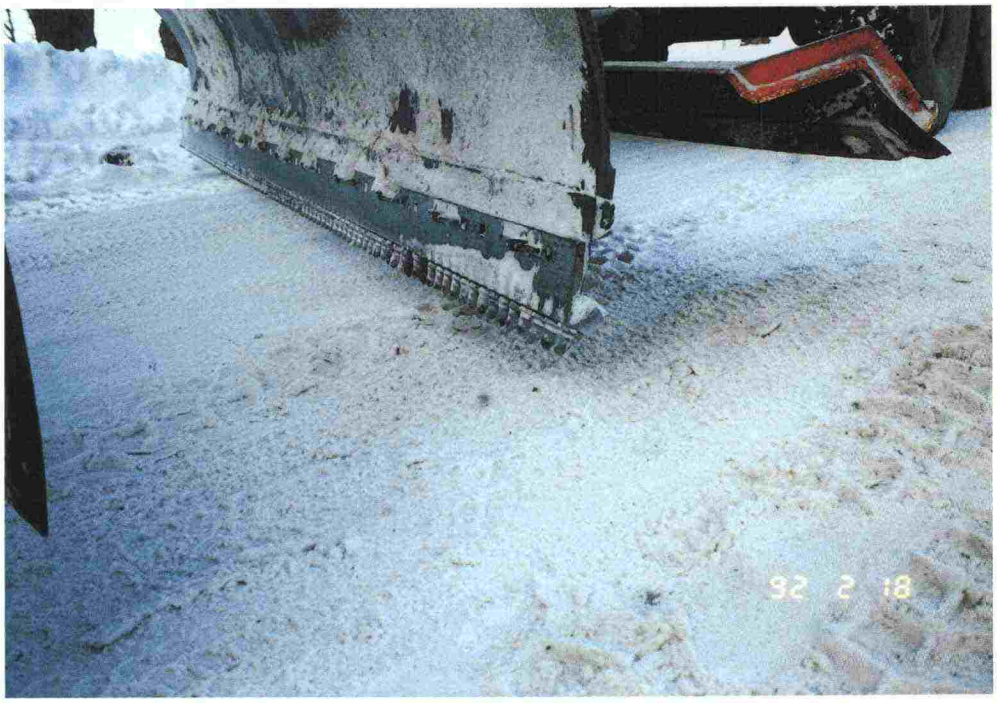
Picture 21: Working procedure at open intersection and at intersection with a traffic island.



Picture 22: Working procedure at a multilane intersection with a traffic island.

Steep hills: If it is possible to operate in the downhill direction only, traffic control needs to be provided.

Pavement types: The pivot type blades can damage pavements, so special care must be taken. On thin, chipping-type surfaces it is not wise to use rough cutting edges.



Picture 23: A pivot type rolling cutting edge.

6.3 Overpasses and Railroad Grade Crossings

It is not allowed to drop snow onto the highway or railroad beneath.

Work at railroad grade crossings must be done in close cooperation with the railroad authorities. Caution must be taken to avoid problems with trains.

6.4 Operation Speed and Grooves

The speed of a motor grader must be carefully controlled to prevent from "galloping" and causing uneven surface. If this occurs the unevenness must be removed immediately. If not, the unevenness grows higher with each pass. Removal of unevenness is achieved by adjusting the leveling angle.

When rough blades are used, the unit must follow the usual driving lanes. This is done to avoid having grooves guide vehicles into the wrong lane.

When leveling with underbody blades, the maximum speed is 20 km/h (13 mph).

7 ICE CONTROL METHODS AND MATERIALS

7.1 General

Ice control operations are done both chemically and mechanically. A bare pavement policy applies for the roads with traffic volumes of more than 1500 on main highways. NaCl is normally used. $CaCl_2$ is used as a liquid or pre-wetter, but seldom in granular form. On low volume roads abrasives are applied when and where needed (snowpacked surface policy). Paved low volume roads are treated with salt in the fall and spring.

In the second half of the 1980's use of salt increased up to 150,000 tons/year. Because salt causes undesirable side-effects to the environment, road structures and vehicles, a goal was adopted to reduce salt application down to the level of 50-60,000 t/y (as in the middle of 1980's). The winter of 1992-93 showed salt usage of 95,000 t (16 % less than in the previous year).

Decreased use of salt does not mean compromising traffic safety. Introducing new salting methods can result in even better conditions of highways. Training of maintenance personnel is one of the key factors in this success.

Effective snow removal is another key factor when minimizing the use of salt. The less snow there is to be melt, the less salt required.

7.2 Chemical Ice Control

Salt is used to prevent ice from forming, to remove already formed ice, and to prevent snow from bonding near freezing point temperatures. The first black ice situations in the fall are the most dangerous. Preventive salting methods such as salt brine work best to avoid black ice: no slipperiness occurs.

Road weather information together with information from weather radars and satellites create a solid basis for chemical anti-icing and de-icing activities. Weather is discussed more in the appendix no. 1.

Chemical ice control is effective, when the road surface temperatures are warmer than -7°C (20°F). If any slush develops after salting, it must be removed as soon as possible.

7.2.1 Dry Salt

It is recommended not to spread dry salt at all, especially not for preventive purposes. If used, it is best suited for snowfall situations. Dry salt should not be spread at higher speed than 30 km/h (20 mph). Dry salt flies away from a roadway before the melting process begins if unfavorable conditions exist, such as winds, turbulence from spreading vehicles and traffic.

7.2.2 Pre-Wetted Salt

The idea of pre-wetting is to increase the weight of the salt particles, to bind fine grains of salt, to make salt sticky and to offer moisture necessary for initiating the melting process. It should be noted, that pre-wetted salt can be thrown away from a roadway almost as easily as dry salt by high volumes of heavy vehicle traffic.

There are two methods to pre-wet salt in Finland. One is with brine sprayed on or before the spinner. Another is by adding water in the box of a truck full of salt. If pre-wetted on the spreader, the amount of liquid can usually be adjusted between 0 and 30 % of the weight of salt to be spread. If pre-wetted in the truck box, a good amount of water is 80-100 l/m^3 depending on the spreader and on how well salt comes out of the spreader.

It is important that the liquid has enough time to penetrate into the salt particles. When pre-wetting in the box, an excess amount of salt should be avoided, because pre-wetted salt is a problem to store.

The maximum spreading speed with the pre-wetted salt is 30-40 km/h (20-25 mph). The higher the speed, the higher the turbulent effect behind the vehicle.

It is recommended to spread salt using a narrow spreading pattern, because more salt remains on the road. On undivided highways the width of 3-4 m onto the middle of a highway is usually good for black ice type situations. During snowfalls the width of 2 m is good when directly applied behind the spreading unit.

Table 6: Application Rates of Pre-Wetted Salt.

Road surface temp. or weather cond.	Black ice type cond.		Freezing rain		Freezing sleet		Snow storm	
	Kg/km	g/m^2	Kg/km	g/m^2	Kg/km	g/m^2	Kg/km	g/m^2
+...-2°C	14-35	2-5			70-175	10-25		
0...-7°C			35-140	5-20				
Stable							70-140	10-20
Variable							70-210	10-30

The figures in the table are recommendations for a 7 m wide highway. Deviations from this table should be based on experience.

Picture 24: Pre-wetting tube at the end of an auger conveyor spreader.

Picture 25: Pre-wetting with water in the box of a truck.

7.2.3 Salt Brine

The advantage of liquid salt applications are that it is spread at very small rates and almost 100 % remains actively on the road. Brine is most commonly produced from NaCl in Finland. $CaCl_2$ is used in those regions that are close to a $CaCl_2$ factory. Ready made $CaCl_2$ brine is the best alternative if only small amounts are needed per year. The concentration of NaCl is aimed at 23-25 %. Ready mixed $CaCl_2$ brine is delivered at 32 % concentration. It is always important to check the concentration, because operations with too low of concentration may fail.

NaCl brine is produced at mixing units in road master stations. Some of them have very large capacities. They often serve more than just one station.

The liquid salt application method is best used for preventive icing, thin ice and hoar frost (rime). A thick layer of ice or snow should not be melted with liquids, because the formed liquid will dilute the salt. If applied during a snowfall, the spreading must be done simultaneously with plowing.

Brines can be spread using either spinner type or spray bar type spreaders. A good spreading speed for spinner types is 40-55 km/h (25-35 mph) and 50-70 km/h (30-40 mph) for spray bar types.

Picture 26: A spray type spreader of liquid salt.

Picture 27: A spinner type spreader of liquid salt.

Advantages of liquid salt application:

* Suitable for preventive ice control
* Good readiness for emergency applications
* Instant or almost instant melting capability
* Small application rates mean reduced salt usage
* One tank of liquid salt goes a long way
* One unit is capable of patrolling in the areas of two or three road master stations outside of normal working hours
* The optimum application rates give the optimum driving conditions with no splash and quick drying
* The roadway is quickly restored to a safe driving condition

Disadvantages of liquid salt application:

* Large initial investments in equipment
* Spray phenomenon behind spreader
* Need for more frequent reapplications due to concern of refreezing
* Impurities may block filters and nozzles

Table 7: Recommendations for the application of NaCl brine at 25 % concentration on a width of 7 m (23 ft).

Road surface temp.	Black ice type cond.		Preventive salting		Snow and sleetfall		Cold weather slipperiness	
	Kg/km	g/m^2	Kg/km	g/m^2	Kg/km	g/m^2	Kg/km	g/m^2
+...-2°C (35-28°F)	35-140	5-20	35-105	5-15				
+...-3°C (35-26°F)					140-280	20-40		
-15°C (35-5°F)							70	10

Notes:

* Example of small amounts of liquids being spread: 14 g/m^2 for a 7 m wide highway means only 1 dl for each meter of highway.

* Road surface should be moist, not wet after liquid application. This fact together with sufficient volume of traffic makes pavement dry rapidly.

* The cold weather slipperiness means temperatures under -10°C (14°F). A small application rate together with traffic makes surface tacky.

7.2.4 Brine Production and Storage

Brine Production

The following facts are good to remember when producing salt brine:

* Salt should be portioned out little by little into the mixing unit in order to achieve quick dissolution.

* Salt concentration is to be measured using a fixed sensor with a digital display or using a simple areometer.

* Compressed air speeds up dissolution of salt.

* The concentration of liquid salt mixture must be 23-25 % (NaCl) or 32 % (factory produced $CaCl_2$).

* The mixing units should be placed indoors to prevent freezing.

Storage of Brines

Storage tanks can be located in connection with the mixing unit or separately. The following facts should be identified:

* The condition of tanks should be checked every year. The tank must be maintained. Proper cleaning after the season is important. Pump must stay in liquid during the summertime - an anti-freeze liquid is recommended.

* Brine must be circulated with a pump at times to prevent stratification of the liquid (concentrated on the bottom, diluted on the top).

* The storage tanks must not be allowed to freeze (warmth of earth, heating element, insulation).

* Leakage to the environment must be prevented (overflow check).

* Waterlines must be large enough to ensure quick process and quick loading of truck tanks.

* The concentration check is very important.

Table 8: Specific weights of NaCl and $CaCl_2$ liquids at different concentrations. Directive values are in bold.

Concentration % NaCl	Specific Weight 0°C	Weight +10°C (40.2°F)	Concentration % $CaCl_2$	Specific Weight +15.6°C (60.1°F)
12	1.092	1.089	22	1.206
14	1.108	1.105	23	1.218
16	1.124	1.120	24	1.228
18	1.140	1.136	25	1.239
20	1.156	1.152	26	1.250
21	1.164	1.160	27	1.260
22	1.173	1.169	28	1.272
23	**1.181**	**1.177**	29	1.283
24	**1.189**	**1.185**	30	**1.295**
25	**1.198**	**1.194**	35	**1.351**
26	1.207	1.202	40	1.410

7.2.5 Preventive Salting

Preventive salting or anti-icing is used to prevent a road surface from freezing and snow from bonding to it. Application of brine is the best method available for that purpose, but pre-wetted salt also works, if the traffic volume of heavy vehicles is low.

Traffic safety can be tremendously improved by constantly using the anti-icing method, especially against black ice. Accurate weather forecasts are needed for successful anti-icing activities. Sometimes an application needs to be applied without full certainty of the forecoming weather. Perhaps it can be determined afterwards, that the salting was not needed. However, when using liquid salt, amounts used are so small that one should not be overly concerned about failures.

Preventive salting can be done at least 1-6 hours before the forecasted freezing, if no excess moisture and/or temperature drop occurs during that period of time. $CaCl_2$ residues stay on the road as long as NaCl residues. It is important to remember that a drop in temperature or excess moisture can cause refreezing of the pavement because of dilution. Sufficient traffic volume is necessary after spreading to dry the pavement.

Preventive salting during a snowfall should be done just after the snow has begun to fall. This is mostly done with pre-wetted salt.

7.3 Alternative De-Icing Chemicals to Salt

Increased chloride contents have been measured in some wells and elsewhere in groundwaters of Finland. So far this has not been a problem significant enough that consideration of alternative de-icers is required.

However, CMA (Calcium Magnesium Acetate) is being used in many reindeer management areas in Northern Finland for test purposes. The reindeer like to eat salt and are therefore gathering at roads endangering motor vehicle traffic and causing more than 4000 accidents annually. The total expense of the damaged property is high.

CMA has a smell of vinegar. It does not attract reindeer and therefore the reindeer stay away and are more afraid of traffic. The use of CMA is expanding to new areas, but other alternatives may be tried as well.

The technique is to mix CMA with sand in a ratio of 15-20 kg of CMA to one m^3 of sand which provides sufficient smell and keeps sand from freezing throughout the winter. This mixture is spread using normal spreading equipment.

CMA is not used in groundwater sensitive areas, because acetates can possibly penetrate through a coarse soil before biodegrading. If acetates reach the ground water and biodegrade there it decreases the amount of dissolved oxygen.

7.4 Enviromental Effects of Road Salt

The presently used de-icing chemicals have many negative impacts. **For the road users** they improve traffic safety, but increase spray and splash phenomenon and corrosion and dirtiness of vehicles. **For the road keepers** salt causes problems by keeping the road surface wet or moist longer thus increasing the wear of the pavements caused by the studded tires. Moreover salt corrodes concrete structures. **Environmentally** salt is harmful because it endangers the quality of drinking water. In addition trees in the road environment suffer from salt.

7.4.1 Preventing the Negative Impacts of Salt

The best way to reduce the negative impacts mentioned above, is by minimizing the use of salt. This has been done by introducing new salting methods and by adjusting the winter maintenance policy of the road regions.

The new methods being used are liquid salt and pre-wetted salt. In the

policies a new classification has been created. It gives the road regions the possibility of maintaining some low volume road sections with fewer salting applications. That means salt is used only, when the weather is poor and it is the only solution.

There are some very sensitive groundwater areas in Finland. These areas are usually shallow and near the surface. In many cases the road slopes have been protected against accidents with hazardous agents transported on the roads. This system works for salt as well. If no protection has been built, only the absolute minimum amount of salt can be applied or in some extreme cases no salt at all. The only alternative then is the use of abrasives.

Bridge concrete corrosion is best prevented by cleaning all bridges along salted highways in the springtime. The corrosion starts when temperatures increase.

Picture 28: Thorough cleaning of bridges is important in springtime.

7.5 Use of Abrasives

On highways with packed snow, the most common way to increase traction between the wheels and the surface is by leveling/roughening roads with a motor grader or truck. At critical stretches like intersections, curves, hills, and bus stops sand is also used. A rain in wintertime usually makes these roads really slippery, so sand or even coarse (0...16 mm) chrushed material must be used the whole length. On narrow roads one way application is enough, on wide roads two way spreading is necessary.

On class I highways sand 0...6 mm is used when the temperature is so low, that salt is not effective.

The sanding of pedestrian and bicycle paths is very important. The operation must be done right away, otherwise people move from the paths to the road shoulders. One side of the path can remain unsanded to facilitate coast and sled traffic. Salt is never used for pedestrian and bicycle paths, because salt sticks to the shoes and is carried into houses.

One of the biggest problems when using abrasives is that they do not remain on the roads. Abrasives also create a cleanup problem in the spring.
According to some studies, fine particles in a material give the best friction immediately after spreading. However, the fines disappear because of traffic. The impact of particle shape is found to be quite minimal.

Taking the above mentioned facts into consideration, it is best to use the type of abrasive, which is the cheapest acceptable and available material in the region. The most common abrasives are sand and macadam. Crushed materials are expensive and it is not clear that they are better.

The coarser the abrasive and the higher the vehicle speed, the more likely windshield damages will occur.

7.5.1 Sand

Pure sand has moderate anti-skid properties immediately after spreading, but it keeps freezing in stockpiles and flies and rolls away easily when the roads are dry. For wet ice pure sand is a good choice.

A suitable application rate for sand is about 150-350 g/m^2. That means about 0.3-0.5 m^3/lane-km. If a sanding operation is done for thin ice, smaller application rates are used. Higher application rates such as 400 g/m^2 or 0.6 m^3/lane-km are required for critical sections.

For spreading activities both roll shaft type spreaders and belt conveyor type spreaders with a spinner are used. A good truck application speed is 30-40 km/h (20-25 mph).

Heated sand application has been tested in many countries. In Finland the results have not been encouraging. The fine particles of sand still fly away and some coarse particles here and there are not effective.

7.5.2 Sand and Salt Mixture

To improve sticky properties of sand and to prevent stockpiles from freezing, salt is added at a rate of 15-20 kg/m^3. More salt can cause packed snow to soften decreasing the driving comfort or it can block the spreading equipment. When the driving speeds are high, sand/salt mixtures do not stay on the road much longer than pure sand.

Sand/salt mixtures are used for I-class roads at low temperatures, when the use of salt is not recommended. The mixture is spread only for critical stretches of highways like interchanges, stopping, and acceleration areas etc.

On class II and III highways sand/salt mixtures are used when the snow packed surface is hard or icy and dry.

The application rates for the class I highways are 100-200 g/m^2. In other locations the recommendations mentioned in the chapter 7.5.1 are followed. The same type of equipment can be used. The spinner type spreaders with pre-wetting capabilities are used to some extent. Good application speeds are 30-40 km/h (20-25 mph).

Sand and salt mixture can also be produced by spraying salt brine onto sand. This method has advantages compared to dry salt and sand mixture such as already moist sand on the road after the application, and just small amount of salt (equal to 5 g salt/m^2).

At long and/or steep hills sand boxes are provided for motorists' use.

Picture 29: Spreading sand/salt mixture with a roll shaft spreader. It provides even distribution over the entire width of the tailgate.

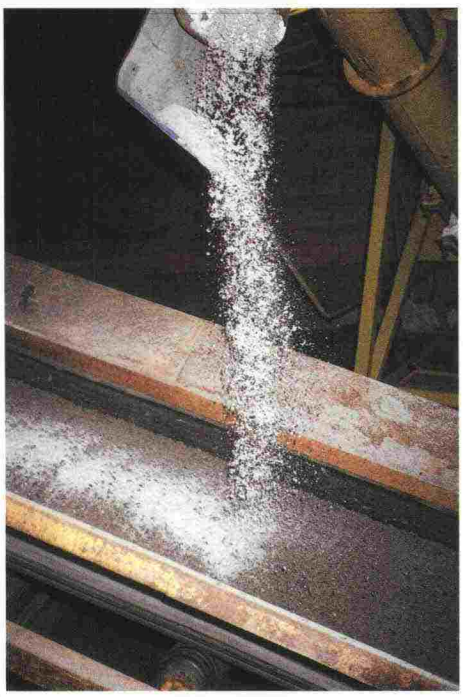
Picture 30: A front buffer mounted sander for the traction and steerability of a truck in slippery conditions.

Mixing Sand and Salt

Salt can be mixed with sand either when filling the storage shed or in minor portions just before needed. The latter way is good, if the mixture is needed only for some short sections and the total usage is small. Pure sand can be stored in spring or early summer, and by keeping doors open the sand dries with good ventilation and will not freeze in the winter.

When mixing the sand and salt in large portions, accurate mixing procedures should be followed. For instance the salt can be portioned out to a belt conveyor while an optic sensor controls the feed of the salt so that it switches off when the belt conveyor stops. An automatic spreader can also be used as a feeder.

The sand/salt mixture is stockpiled high and loose to prevent freezing.



Picture 31: Salt being portioned out to a belt conveyor. An optic sensor controls the feed.

7.6 Quality Requirements of Anti-Skid Materials

7.6.1 Abrasives

Abrasives must not include humus material, because these particles are light and are easily blown away. Angularity and roughness of particles sometimes help the material to stay on the roadways.

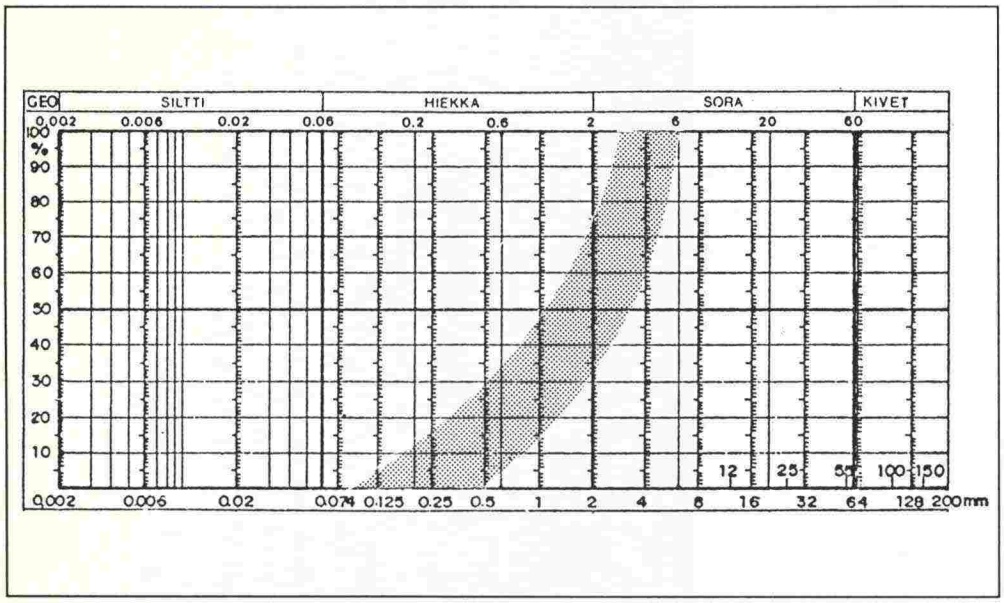


Figure 1: Grading band of abrasives used on main highways.

7.6.2 Sodium Chloride

The maximum grain size of sodium chloride is 5 mm and the maximum moisture content allowed for stockpiling is 1,0 %. The sodium chloride content must be at least 96 %. Salt used for brine production must not have more than 0.3 % non-soluble solids. In addition salt must not have inpurities that hamper the spreading of salt. Sodium chloride does have an anti-clogging agent.

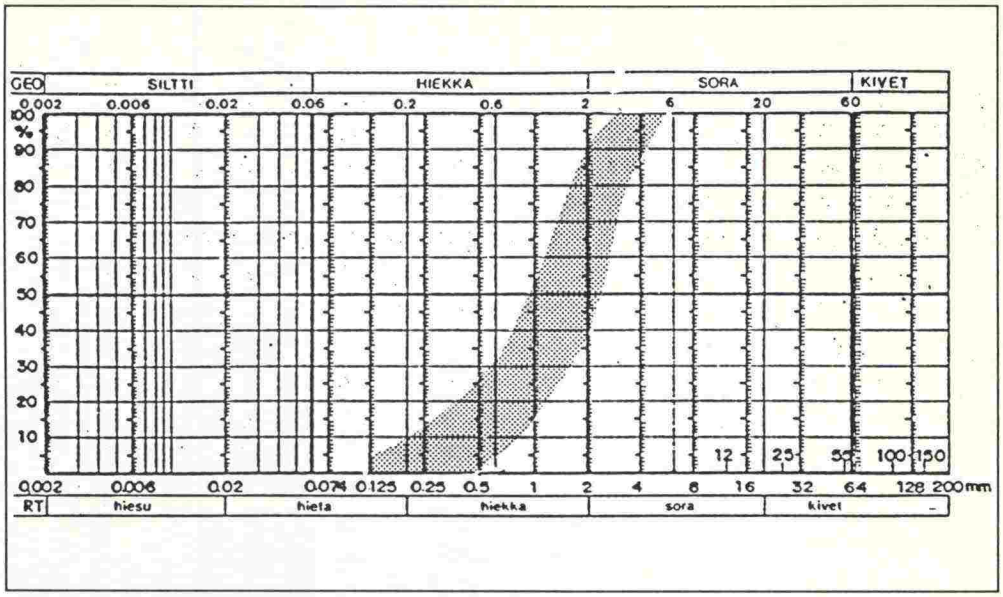


Figure 2: Grading band of sodium chloride.

7.7 Material Storage

7.7.1 Pure Abrasives

Rock silos work best for storage of pure sand and other pure abrasives. If a site is not available, they should be kept in barns, or at least be covered by tarpaulins. Macadams without fines do not freeze when stored outside.

7.7.2 Sand/Salt Mixtures

Sand/salt stockpiles always need to be covered. Ground must be of non-permeable material and the water outlets must be controlled (this also includes water melted from removed snow).

It has been determined that 95 % of salt mixed with sand dissolves with free water and flows away before the mixture is used, if stored in an open air stockpile. Therefore open air stockpiles are not allowed in Finland.

7.7.3 Sodium and Calcium Chlorides

Sodium and calcium chlorides in bulk quantities are always stored in specially built storage buildings with ground protection and drainage systems. The outside loading and handling areas must be paved with impermeable materials. Accumulated water must be directed to the waste brine tanks or to large lakes or to the sea.

Salt sacks are stored in places where the sacks can not be damaged. Salt clumps can be used in brine production.

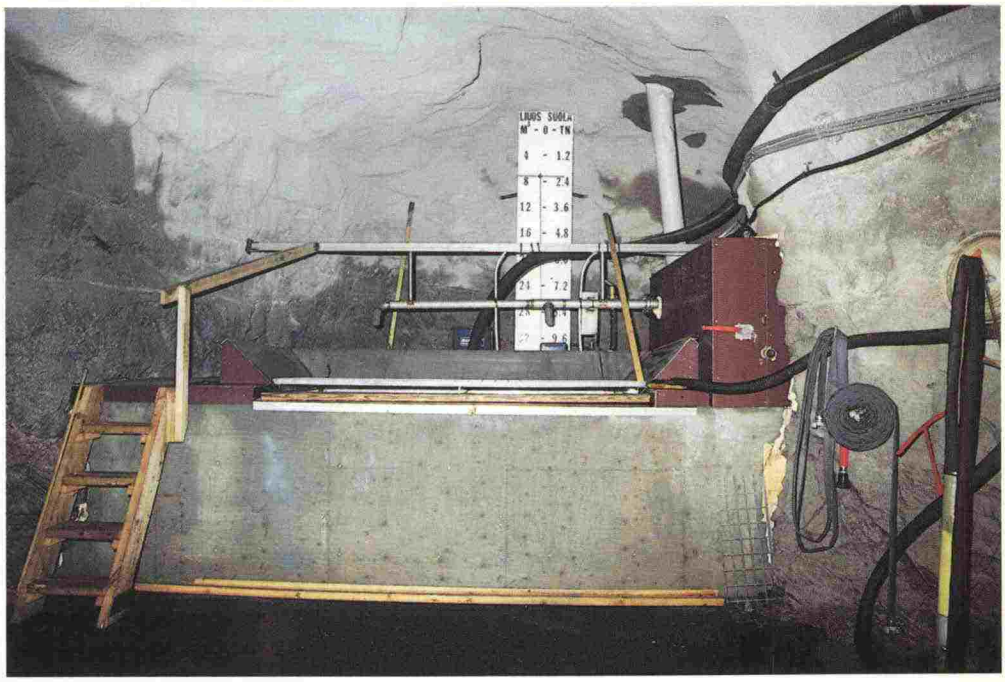
In addition, there are laws and regulations that apply to the storage of salt.

7.8 Equipment Needed for Anti and De-Icing Activities

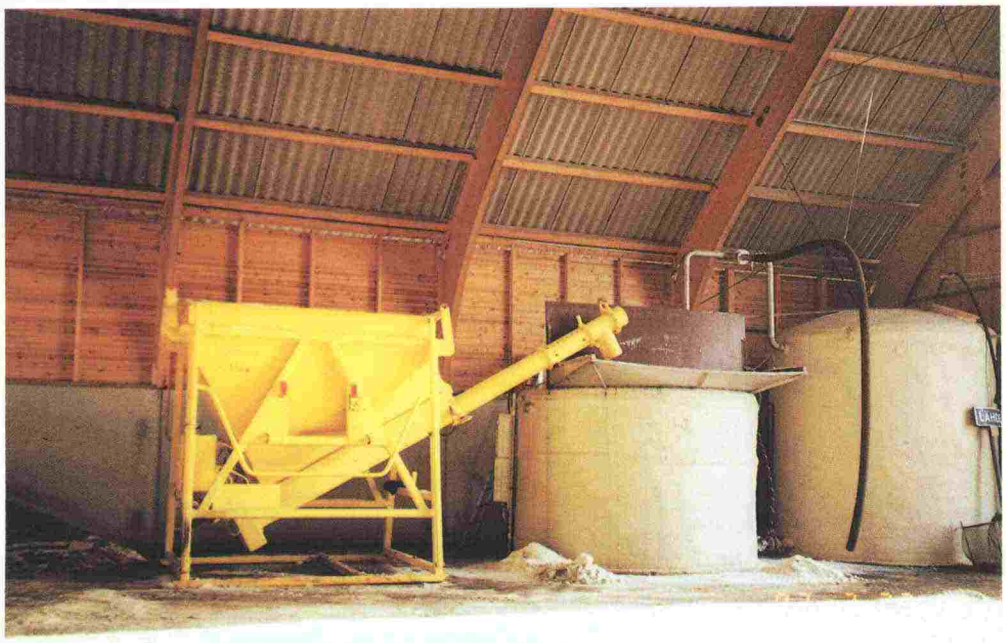
7.8.1 Brine Production Units

Simple units for a temporary or small scale production can be built from used tanks and other equipment. For a high capacity production more efficient units should be used. The high capacity production units are partly developed by the road administration and partly by the private enterprises. When acquiring new equipment, the following items should be considered:

* Additional capacity should be planned for future needs
* Sufficient water inlet capacity needs to be available
* Site requirements
* Pump capacity requirements
* Utilization possibilities of earth warmth
* Compressed air use preparations
* Overflow control requirement



Picture 32: A high capacity brine production unit designed by the road administration. Compressed air can be utilized. Picture taken inside a rock cave.



Picture 33: A factory made high capacity brine production unit with a portioning device made of fiberglass. Compressed air can be utilized.

7.8.2 Salt and Sand Spreaders

Both roll shaft and spinner type sanders are used to spread abrasives. Usually only spinner type spreaders are used for salting activities. Liquid chemicals are spread with both spinner and spray bar type spreaders. The combination type spreaders are the newest design. They facilitate all kinds of materials from granulars to liquids to be spread with the same unit.

The spreaders must meet the requirements of accuracy. They have to be calibrated once in a while according to a utilization rate and material being spread. If a spreader is used often for many kinds of materials it may be necessary to check the calibration in two week intervals. The hydraulics of trucks must also be checked periodically. The foremen should check to be certain all drivers do this.

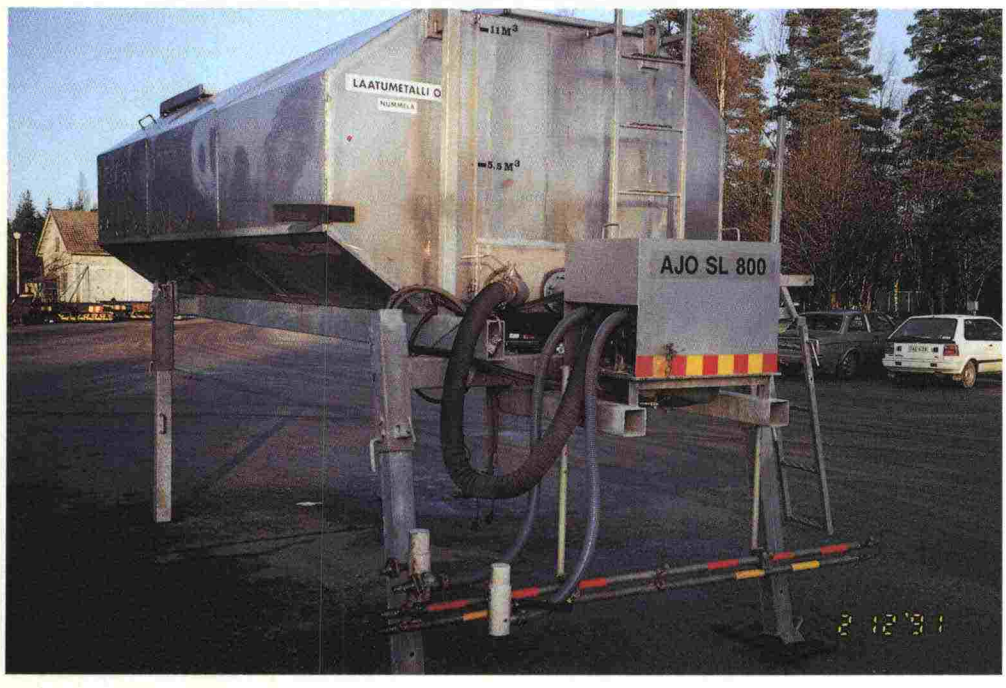
The application rate of spreaders must remain stable in spite of changes in the driving speed. The maximum speeds are:

Dry salt 30 km/h (20 mph)

* Pre-wetted salt 30-40 km/h (20-25 mph)

* Liquid salt with a spinner type spreader 40-55 km/h (25-35 mph)

* Liquid salt with a spray bar type spreader 50-70 km/h (30-40 mph)



Picture 34: A simple and cheap spray bar type spreader for liquids.

Picture 35: This combination spreader is able to spread salt/sand, pre-wetted materials, and liquids.

Picture 36: Macadam of 4-8 mm spread onto packed snow.

8 SPECIAL WINTER ACTIVITIES

8.1 Preventing Drainage from Freezing and Melting Culverts

Because of freezing the water pressure, underground or elsewhere, starts to rise. The water under pressure rises to the ground level and then freezes. If this continues, water rises to the road and ice blocks the culverts. The overflow from the ditches can also cause trouble for farm owners.

The most problematic places are worth taking protective (insulation) measures before winter. In some situations structural road improvements must be considered.

8.1.1 Melting Ice from Culverts

Culverts blocked with ice should be melted before the thawing period starts. Steam generators work well for that. Melting operations for blocked culverts at intersections may belong to different road keepers (road administration, municipalities, private road boards).

8.1.2 Preventing Drainage from Freezing

The winter phenomenon when the rising water freezes on the ground, is called crusty ice. Susceptible places for this are:

* Natural ditch above or under a culvert
* Some culverts
* Side ditches of a road section
* Outer slopes oozing with water
* Especially in Northern Finland, water flowing from peatland via side ditches
* Water flowing from the surface of a rock cut

Crusty ice appearance varies from year to year according to conditions of snow and temperature.

Using routine maintenance methods, crusty ice can be prevented by the following means:

* By using an electric heating wire in a casing pipe on a ditch/ culvert bottom, or under a bridge.

* Both ends of a culvert are insulated with hatches or plastic film, eventually covered by snow.

* Water level is kept at a certain level by damming. The ends of culverts are then insulated above the ice cover.

* Double culverts: one of them can be closed for the winter.

* A smaller culvert in diameter can be set into a larger culvert in order to lead water through it during the winter. In some cases the small culvert can be closed for the winter and opened only for the spring. Then the waterflow is melting the main culvert as well.

* Crusty ice above a culvert can be controlled by compacting the snow in a ditch in order to cause crusty ice formation from further away.

* Several dams are built on the upper level of a ditch. Then the crusty ice can not reach the road during the winter.

Sodium or calcium chlorides are not allowed to be used to keep water running in drains.

The structural measures in preventing crusty ice are insulation of the whole culvert, a special winter culvert built under the main culvert level, an overflow culvert built above the main culvert level, a culvert placed according to the natural gradation and the use of crown ditches and underdrains.

When removing crusty ice steam generators, excavators and motor graders with accessories can be used. Side ditches to be opened should be excavated as narrow and deep as possible to minimize an evaporation effect. If a snowfall covers the excavated ditch after that, the optimum circumstances exist.

Appendix 1.

Yrjö Pilli-Sihvola, Meteorologist, FinnRA:

WEATHER AND WINTER MAINTENANCE

General weather forecasts, road weather stations and personnel experiences are the main sources for road weather information.

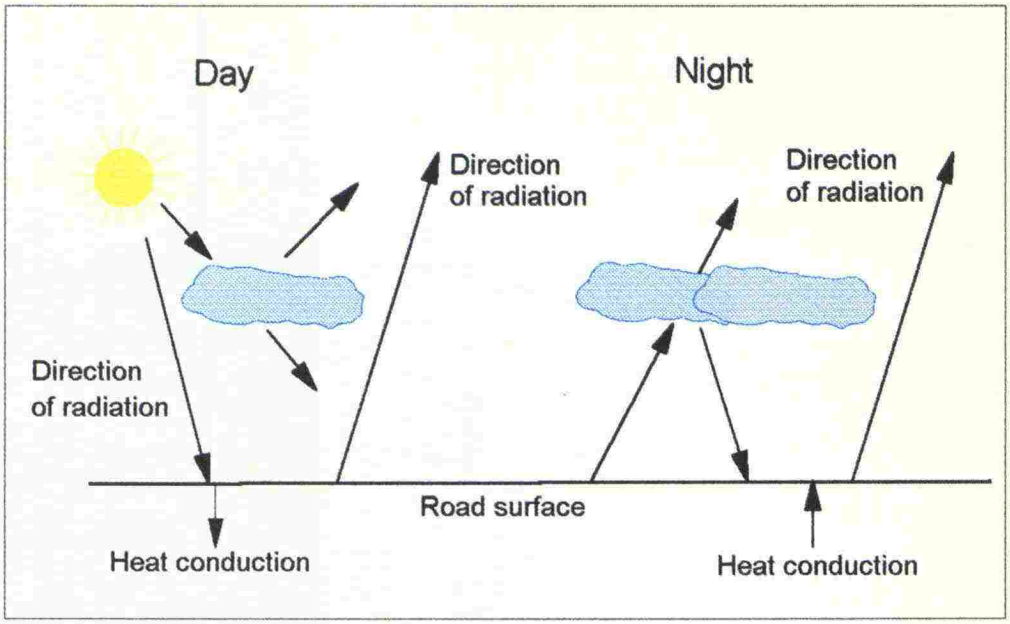
The newest system for road weather information was introduced during the winter of 1991-92 in Finland. The road weather station network covers the whole country. The network is dense in the southern and coastal regions and sparse in the northern regions.

Slipperiness may form in many ways:

Freezing of road surface	Precipitation and fog
* Wet surface freezes	* Rain onto a cold surface
* Hoar frost/black ice	* Freezing rain
* Abating slipperiness	* Snow storm
	* Fog

Wet Surface Freezes

When the sun radiation decreases and ends during evenings and nights, the radiation from the highway to the air is greater than vice versa. The clearer the sky, the greater the radiation to the air. The longer this situation continues, the colder the road surface becomes. The road surface temperature decreases more quickly than the air temperature and the road surface becomes colder than the air. This is called an out-radiation situation. If the road surface is wet, it will freeze before the air temperature reaches 0°C (32°F). The air temperature may not drop under zero at all.



Picture 1: Simplified radiation balance scheme.

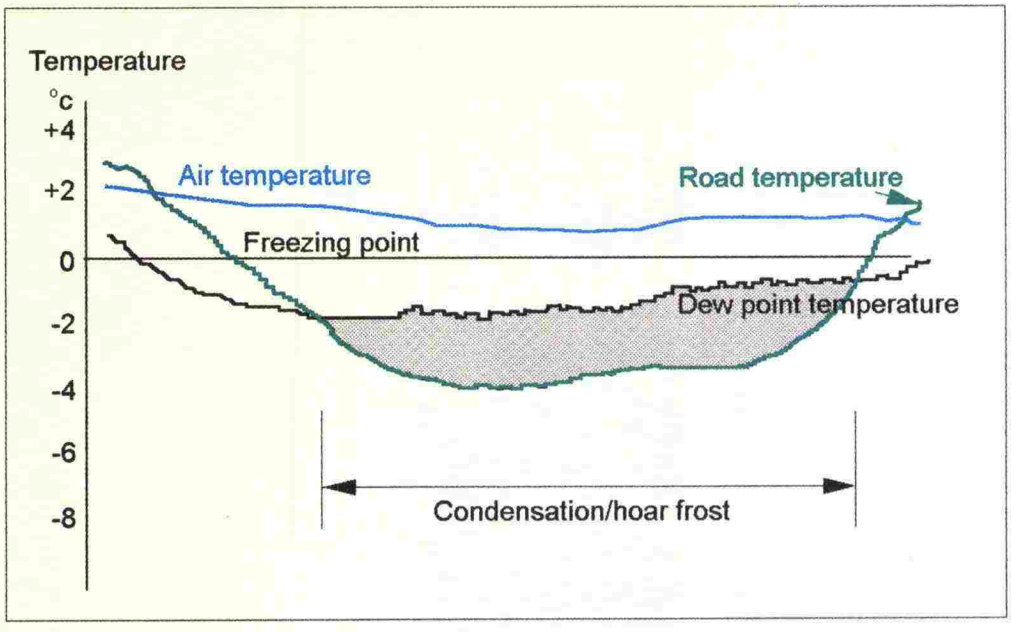
Hoar Frost

Hoar frost is a result of out-radiation situations. Traffic flow makes the hoar frost slippery like black ice. Hoar frost can form on a dry road but forms more easily on bridge decks, because there is less warmth capacity.

The dew point temperature is the temperature where moisture of air starts to condense onto surfaces such as roads.

When the road surface temperature drops under the dew point temperature, the moisture starts to condense onto the road surface. The greater the difference between the road surface temperature and the dew point temperature and the longer the situation continues, the more moisture condenses.

Hoar frost is also formed when the road surface temperature is below the freezing point and warm, moist air is blowing onto the cold pavement. The hoar frost melts partly due to traffic and the mixture of ice and water makes the surface slippery.



Picture 2: Hoar frost forms in the darkened area between the dewpoint and air temperature curves.

Slipperiness Caused by Warming Weather

This condition is a close relative to the hoar frost. Warm air affects the road by adding more moisture than cold air. The dew point temperature is raised leading to the condition described above.

This can lead to very difficult situations, because the temperature may have been very low. Because the temperature is low, salt may not be effective. If the temperature changes eg. from -30°C (-22°F) to -20°C (-4°F), anti skid measures become necessary. Usually this is done by sanding, but small amount of liquid salt together with a sufficient amount of traffic makes the surface tacky.

This kind of situation is typical in the spring and it can continue for a couple of days.

Rain on Cold Roads

When rain falls on a road surface which has a temperature below the freezing point, rainwater freezes forming ice. Because roadway surface temperatures vary, slipperiness may be unexpected to the driver.

Freezing Rain

Freezing rain can occur during some warm weather fronts. There is warm air above cold air and when the rain drops fall down, they cool in the cold air layer to some degrees below zero. The drops freeze when meeting the road surface and it becomes slippery. The ice layer can be thick at times and salt is often ineffective.

Snowstorm

Snow is composed of ice crystals. If the temperature is low, snow is more crystal-like. Wet snow forms more slippery conditions than dry snow. Snow can result in extremely slippery conditions, if it falls onto an ice layer.

Snow intensity is measured in water millimeters. Roughly one mm of water equals one cm of snow. In forecasts a 5 mm precipitation means more than 5 cm of snow.

Sleet is a mixture of snow and rain.

Fog

Fog can be local or it can cover large areas. Local fog is caused by local atmospheric conditions. Large area fog is usually connected to a warm and moist low pressure area. Fog can endanger traffic safety significantly when the visibility is less than 200 meters or yards.

If the temperature is below zero, fog can condense onto a road surface. Fog drops are very small and therefore the surface ice layer usually remains thin.

Appendix 2.

1. HIGHWAY MOISTURE DESCRIPTION

Definition	Water g/m²	Description
Little moist	5 - 20	Detectably dark pavement
Moist	20 - 50	Clearly dark pavement
Wet	50 - 200	Spray phenomenon starts
Very Wet	200 - 400	Small drops of water in the air
Flowing	400 -	Flow according to gradient, splash

2. WATERFILMS AND CORRESPONDING ICE THICKNESSES

Water g/m²	Ice thickness mm
10	0,01
30	0,03
100	0,10
300	0,30
500	0,50

1 mm = 25/64"

3. FREEZING POINTS ACCORDING TO MOISTURE AND SALT CONTENT

Description	Water g/m²	Freezing points					
		Salt g/m²					
		2	5	10	20	30	
Little moist	10	-16	-21	-21	-21	-21	°C
		3	-6	-6	-6	-6	°F
Moist	30	-3	-10	-21	-21	-21	°C
		26,6	14	-6	-6	-6	°F
Wet	100	-1,5	-2,5	-7	-11	-21	°C
		29	27,5	19,4	12	-6	°F
Very wet	300	-0,4	-1	-2	-3,5	-5	°C
		31	30	28,4	26	23	°F
Flowing	500	-0,1	-0,4	-1,5	-2	-3	°C
		31,8	31,3	29	28,4	26,6	°F

4. FREEZING POINTS FOR LIQUID 23 % NaCl SPREAD ON THE ROAD

Description	Water g/m²	Freezing points				
		Liquid g/m²				
		5	10	20	40	
Little moist	10	-5	-6	-10	-16	°C
		23	21	14	3,2	°F
Moist	30	-1	-4	-5	-9	°C
		30	25	23	16	°F
Wet	100	0	-1	-2	-4	°C
		32	30	28,4	25	°F
Very wet	300	0	0	0	-2	°C
		32	32	32	28,4	°F
Flowing	500	0	0	0	0	°C
		32	32	32	32	°F

ISBN 951-47-8115-5
TIEL 2230006E