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MANAGING SPRING THAW WEAKENING ON LOW VOLUME ROADS

Problem description, load restriction policies, monitoring and rehabilitation

ROADEX II
NORTHERN PERIPHERY

THIS PROJECT IS BEING PART- FINANCED
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April 2005

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ROADSCANNERS

PREFACE

This is a final report from the Phase II subproject 2_3 survey of the Roadex II project, a technical transnational cooperation project between the Highland Council, the Western Isles Council, and Forest Enterprise from Scotland; the Northern Region (formerly Troms district) of the Norwegian Public Roads Administration and the Norwegian Road Haulage Association; the Northern Region of the Swedish National Road Administration; and from Finland the Regions of Central Finland and Lapland of the Finnish Road Administration, as well as Metsähallitus Region of Eastern Lapland, the Forestry Centre of Lapland (Lapin Metsäkeskus), Stora Enso Metsä, and Metsäliitto, Procurement Area of Northern Finland. The Roadex project is partly financed by the ERDF IIIB Northern Periphery Programme. The lead partner in the project is the Highland Council from Scotland and project consultant is Roadscanners Oy from Finland. Roadex II project Chairman is Ron Munro from the Highland Council and project manager is Timo Saarenketo from Roadscanners.

The report summarizes the work done on Task 2_3 “Spring Thaw Weakening” of the Roadex II project. The report will describe the theory behind spring thaw weakening and different load restriction policies used in the cold climate areas. It will also report the results of the field tests done in Scotland, Sweden and Norway and present some new structural solutions which have been found to work well at spring thaw weakening sites. Finally, new technologies for both road owners and/or road users that could be used in more effective spring thaw weakening management will be revealed.

The authors would like to express their gratitude to Ron Munro and Frank MacCulloch from Scotland, Johan Ullberg from Sweden as well as Seppo Kosonen, Tapani Pöyry, Timo Hyvönen, Tarmo Posti and Kari Parikka from Finland for helping with the field test arrangements. Special thanks to Nuutti Vuorimies from Finland for providing survey data for this research and also to Pauli Kolisoja from Finland, Svante Johansson from Sweden and Geir Berntsen from Norway for their valuable help in this survey.

Timo Saarenketo and Saara Aho wrote this report, Virpi Halttu has edited it, Kent Middleton has checked the language and Jaakko Saarenketo has given valuable help with graphics and data analysis, all of the aforementioned people are from Roadscanners. In addition, all of the Roadscanners crew and many others have given help with data collection and analysis.

Finally the authors would like to acknowledge the Roadex II Steering Committee and the Road Condition Working Team for its encouragement and valuable guidance in this work.

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CONTENTS

ABSTRACT

The ROADEX II Project is a co-operation aimed at developing ways for interactive and innovative management of low traffic volume roads in the Northern Periphery Area in Europe. The goal for subproject 2_3 “Spring Thaw Weakening” was to collect information regarding one of the most difficult challenges in low volume road condition management in cold climate areas, managing road condition during the spring thaw weakening period. This has to be done in a way that minimizes the impact of transportation problems on local livelihoods without destroying road structures or reducing the service level of the road for the rest of the year. The survey has followed the Roadex II Project phase II theme of “understanding and analysis” by using new technologies to monitor spring thaw problems and then analysing the problem sections so as to better understand the processes behind the problems.

The report has six major parts. The first part of the report presents the theory behind spring thaw weakening, the scope and the scale of spring thaw problems as well as the different load restriction policies used in the cold climate areas. The second part of the report summarizes the key results from the extensive field testing done at the Roadex test sites. The third part of this report presents a new classification for spring thaw weakening phases that can be used in monitoring and communication terminology when describing the status of spring thaw but is should also be used in the decision making process involved when deciding whether to remove or implement load restrictions. In the fourth part a new classification for spring thaw weakening sites is presented. This classification is important in order to be able to select an optimum strengthening method for each type of spring thaw problem. These strengthening techniques and structures and their life cycle costs are presented in the fifth part of this work. The sixth part presents new technologies and ideas for better spring thaw weakening management on low volume roads.

The Roadex II survey results regarding seasonal changes and spring thaw weakening produced valuable information regarding the processes behind road damage and the complexity of these processes. Test results indicated that standard truckloads can easily break the road during the weakest phases in spring incurring major costs to road owners as well as an unpleasant ride for other road users during the rest of the year. On the other hand it can be estimated that in Finland and in Sweden, for instance, every day of load restrictions results in more than one million euro extra cost for the forest industry. The results also reveal that the critical weakening phase is often quite short and that is why good monitoring systems with better spring thaw weakening models will generate major savings for the haulage companies using low volume roads. Other promising solutions that should be studied further are the idea of recovery times after a truck pass and the use of CTI (central tyre inflation) techniques or special axle configurations to reduce the risk of damaging roads during the spring thaw. However the long term goal should be to repair and strengthen all of the weak road sections, and only the weak sections, so that load restrictions would no longer be needed.

KEY WORDS: Roadex, low volume roads, spring thaw weakening, dielectric value, DCP test, Percostation, Load restrictions.

1 Introduction

1.1 Roadex II project

The ROADEX II Project is a co-operation aimed at developing ways for interactive and innovative road management of low traffic volume roads in the Northern Periphery Area (figure 1). One of the major goals of the Project is to strengthen and reinforce the first ROADEX technical exchange and co-operation that was established in the Northern Periphery during the year from 1998 to 2001.

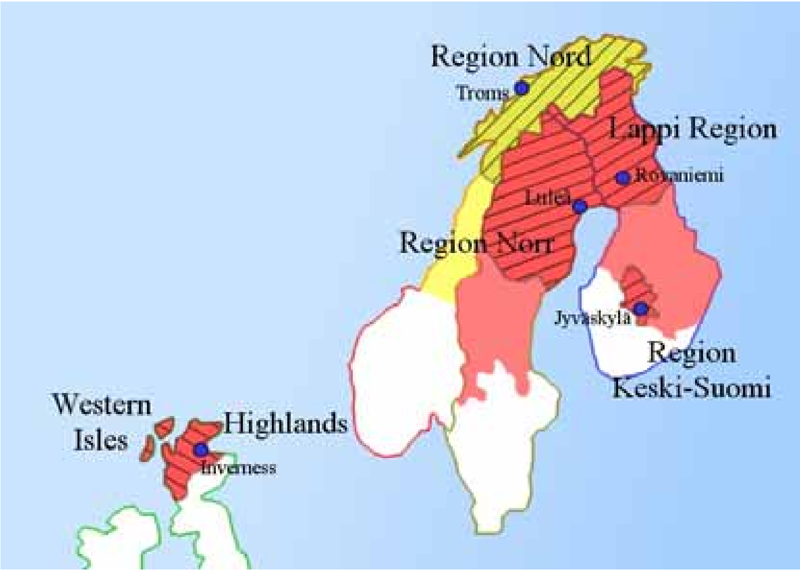

Figure 1. Northern Periphery Area and Roadex II partners.

Within this overall strategy the specific objective of ROADEX II was to develop ways for interactive and innovative road condition management of low traffic volume roads integrating the needs of local industry, Road Districts and society at large. This goal involved developing models, assessment methods and tools to improve local Road District road condition management taking into account the views of road users.

The partners within the Project comprised public road administrations, forestry organizations, forest companies and haulage organizations from the following regions in the Northern Periphery of Europe: The Scottish Highlands and the Western Isles, the northern regions of Norway and Sweden, and the regions of Central Finland and Lapland in Finland. The Roadex cooperation maintains a web site at www.roadex.org.

The Roadex II project was conducted in three phases during 2002-2005: (I) Problem identification, (II) Understanding and Analysis, and (III) Innovation and Testing.

The goal for the phase I work was to provide a road user's perspective on the condition of the road network in each test area. These areas were chosen to be representative of each partner road district. The survey focused on road users´ transportation needs and opinions on the general condition and trend of the road network in summer and winter, traffic safety issues, types of problem encountered with transportation industries as well as opinions regarding the level of cooperation with local road authorities.

Phase II focused mainly on the technical details of the road condition problems shared throughout the regions. These problems, identified in the Roadex I project, included the permanent deformation of low volume roads, material treatment techniques, drainage problems, spring thaw weakening and its management, and managing road sections resting on peat. The phase also included a subproject that focused on the problems that would arise if low volume roads were allowed to continue to deteriorate. A final subproject evaluated current environmental guidelines for low volume roads through all the partner districts and produced a common environmental checklist.

The final phase of the Project, Phase III, will focus on preparation of proposals on which to base new low volume road condition management policies suitable for Northern Periphery areas. It will also summarize the findings of the phase I and II results in the form of new structural innovations and best practise methods. Finally phase III will briefly review the possibilities that modern information technology can provide for low volume road condition management.

1.2 Spring thaw weakening management on low volume roads

This report presents the results of the surveys carried out in Phase II during 2002-2004. The goal for subproject 2_3 "Spring Thaw Weakening" was to collect information regarding one of the most difficult challenges in low volume road condition management in the Northern Periphery area, managing roads during the spring thaw weakening period in a way that minimizes the impact of transportation problems on local livelihoods without destroying road structures or reducing the service level of the road for the rest of the year.

The survey has followed the phase II theme of "understanding and analysis" by using new technologies to monitor spring thaw problems and then analysing the problem sections so as to better understand the processes behind the problems. As a part of this research, a review of the literature concerning current spring thaw management practices throughout the world has been done. Finally, the report presents new tools and classification systems to help engineers to better focus on the problems and find more economical and sustainable solutions in managing spring thaw problems in their low volume road networks.

The Roadex II project has collected an extensive amount of data from the project test sites and reports, and detailed analyses will be published in scientific symposiums and publications. Data is also available on the Roadex web pages.

2 Spring thaw weakening in low volume roads - background

2.1 General

Seasonal changes and freeze-thaw cycles and the damage they cause are the most significant factor affecting the road condition of northern cold climate road networks in Europe, Asia and North America. In the United States, the AASHO research program studied the appearance of pavement distress during different seasons (White and Goree 1990) and, according to the results, 60 % of the distresses appeared during the springtime when the relative amount of traffic was 24 %. During the summer time the relative amount of new pavement damage was only 2 % when the relative traffic amount was 30 %.

However, freeze-thaw processes also cause major problems in high elevated areas in countries with warmer climates, for instance the percentage of the road network sensitive to freeze thaw damage in Romania is 50 %, in Hungary 40 % and in France 20 % (Isotalo 1993). Frost damage is visible in roads as uneven frost heaves and longitudinal and transverse cracks (figure 2), but above all as softening of the road structure and permanent deformation (figure 3) during the spring thaw period. In the worst scenario driving on these roads can be impossible.

Figure 2. Longitudinal crack caused by differential frost heave in road 19773 in Rovaniemi, Finland.

Spring thaw weakening damage is the biggest problem on "unbuilt" gravel roads. For instance in Finland almost one half of Finland's 28.000 km gravel road network suffers some form of thaw damage. According to the annual Finnish spring thaw structural damage inventory results from 1998-2002 an average of 1020 km of road with severe visual spring thaw damage was observed. This represents 3.5 % of the gravel road network (Saarenketo & Perälä 2003). There are also major area differences with respect to the appearance of spring thaw problems in gravel roads (figure 4). The changes can be related to changes in soil conditions but also to the development history of the low volume road network as well as how heavy transports use these roads.

Figure 3. Permanent deformation in road 229 in Senja Norway.

Spring thaw weakening is also a major problem on paved roads and especially on weak roads with surface dressing pavement (see figure 3). The difference between gravel roads and paved roads is that spring thaw damage in gravel roads is much easier and cheaper to repair; many times problems can be fixed with a grader.

Figure 4. Public gravel roads with spring thaw problems in Finland (Virtala 2004).

2.2 Road owner problems

Traditionally road administrators have endeavoured to prevent spring thaw damage by implementing load restrictions or even closing the road. Research done by the World Bank in (Isotalo 1993) clearly showed the economical benefits, for road administrations, of using load restrictions in severe winter conditions (table 1).

Table 1. Cost saving attributed to load restrictions in eastern and Central Europe (Ray et al. 1992, see also Isotalo, 1993 and C-SHRP 2000). The calculations are based on the occurrence of severe winter once every 20 years.

Country	**Percent of road network sensitive to freeze thaw**	**Annual daily traffic**	**Cost of severe winter with load restrictions (Mill. USD)**	**Cost of severe winter without load restrictions (Mill. USD)**	**Associated cost saving (percent)**
Bulgaria	25	2250	200	2500	92
CSFR	30	2700	300	2300	87
Hungary	40	2900	300	3100	90
Poland	15	2240	400	1800	75
Romania	50	2700	600	4400	86
Yugoslavia	45	2100	900	5400	83
France (1985)	20	4900	4,800	8,000	40

The use of spring load restrictions also increases the pavement lifetime. According to U.S. Federal Highway Administration (FHWA) research results (1990) a pavement load reduction during the spring thaw increases pavement lifetime by 62 % and a 50 % reduction increase pavement life by 95 %.

2.3 Road user problems

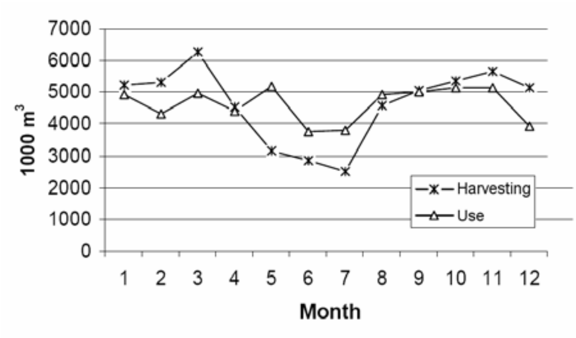

Figure 5. The volume of monthly timber harvesting and its industrial use in Finland (after Pennanen and Mäkelä 2003)

Spring thaw weakening and load restriction measures incur major extra costs for industries using heavy transport vehicles. In Finland, the extra costs to the forest industry, due to spring thaw weakening, has been calculated to be 100 M€, of which 65 M€ comes from public roads (Pennanen and Mäkelä 2003). The corresponding value for the forest industry in Sweden has been evaluated to be roughly 100 M€/ year (VV Publ 2003:99). The Swedish figures also include extra costs caused by roads with permanent restrictions (BK2 and BK3) and extra costs caused by roads with high roughness values (SkogForsk 1999). The main reason for extra costs for the paper industry is that timber harvesting cannot be arranged to the same degree as production (figure 5) and this forces the industry to use timber storage. Figure 6 presents the distribution of extra costs due to seasonal changes in timber harvesting (Pennanen and Mäkelä 2003). In Norway the evaluated extra costs to road users have been lower, partly because forest industry does not have such an important role as it does in Finland and Sweden. According to the BUAB project the extra costs to all road users caused by load restrictions in early 1990´s was evaluated at 40 M€ (Roadex 2001, Refsdal et al. 2004).

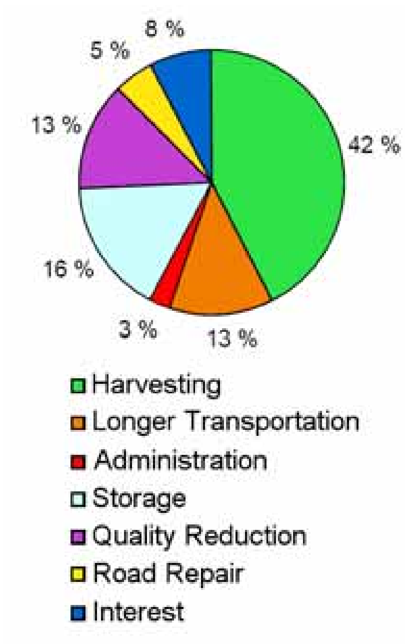

Figure 6. The distribution of extra costs to the forest industry due to seasonal changes (after Pennanen and Mäkelä 2003)

Pennanen and Mäkelä (2003) have calculated extra costs due to spring thaw problems for loaded timber trucks on the most severe spring thaw sections to be 150 €/truck km and on the easiest spring thaw weakening damaged sections to be 75 €/truck km. In Minnesota extra costs for road users has been calculated in the form of increased truck vehicle kilometre (VKT) and in Lyon County this value was 13 % (Levinson et al. 2004).

3 Factors affecting spring thaw weakening

3.1 General

The term "spring thaw weakening" has different meanings in different languages. In general, spring thaw weakening can be defined as a decrease in the bearing capacity of a road during the period in which the frozen road layers thaw during the spring (figure 7). But frost thaw weakening can also be related to weakening of the road after freeze-thaw cycles. There have also been different interpretations of the term "spring thaw weakening" where it is sometimes also used to mean the same thing as "spring thaw damage." In many countries the same word is used to describe both of these expressions, in Finnish, for example, the same word is also used to describe weakening of the road during the heavy rains in fall.

Figure 7. Typical spring thaw damage section on a gravel road near Troms in Norway.

In this report, the term, "spring thaw weakening", refers to both the weakening and the resulting damage due to traffic loads. Launonen et al. (1995) listed the following factors as being necessary for the appearance of spring thaw weakening:

- Road and/or subgrade soil freezes
- The material is frost susceptible
- Freezing front has enough water available
- During the thawing period the water, released by the melting segregation ice (figure 8), stays in road structures or subgrade soils, thus weakening the structure
- Road is subject to loads during the thawing period

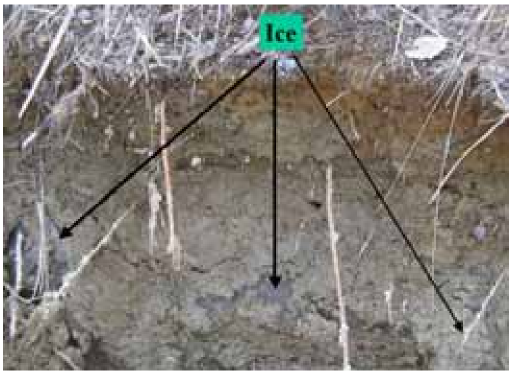

Figure 8. Ice lenses in a silty subgrade during the thawing period in 2003 at Kuorevesi Percostation. Photo Nuutti Vuorimies

If any one of these factors is absent there is no risk for spring thaw damage.

The processes behind the spring thaw weakening are described in more detail in the sections following:

3.2 Thermodynamics – basic principles

In order to better understand the mechanisms behind seasonal changes and especially the spring thaw weakening process one must understand the basic principles of thermodynamics. In general, the road structure can be considered to be a thermodynamic system, that can change along with its surroundings both material, mainly water, and energy. This system is thermodynamically balanced if its properties do not change over time. In order to be called thermodynamically balanced the system must have 1) temperature balance, 2) chemical balance and 3) mechanical balance. A road that is exposed to daily sun radiation, seasonal temperature changes, rainfall and snowfall and changes in the ground water level and is subject to dynamic load cycles caused by heavy vehicles cannot be considered to be thermodynamically balanced and that is why thermodynamics should be always considered when studying seasonal changes.

The main transmitter element trying to balance the thermodynamic instability in a road structure is water and it plays a critical role in almost all road failures. In general, the water in the road structures and subgrade soil can be classified into: 1) hygroscopic water, which can be also called adsorption water, 2) viscous or capillary water and 3) free water. When evaluating the mechanical performance properties of materials it is important to know how much free water has filled the pores in the material. The best way to do this is by measuring the dielectric properties of the materials, which also serves as a measure of the amount of volumetric free water content in material. A detailed description concerning water in soils and its electrical properties is given by Saarenketo (1998).

Soil suction theory and principles of suction force have been used to explain the relationship between thermodynamic properties and the strength and deformational properties of road materials and subgrade soils. Soil suction describes the energy level, also known as Gibb´s free energy, at which water is bonded to a particle surface and that which is needed to release bonded water molecules to free water (Edris and Lytton 1976, Fredlund and Rahardjo 1993). The most important components affecting the mechanical performance of unbound road structures and subgrade soils are 1) matric suction, 2) osmotic suction and 3) cryo suction. The sum of matric suction and osmotic suction is also called as "total suction". Matric suction is mainly affected by pore voids ratio, voids' size and the amount of fines in the material, while the amount of ionic compounds affects mainly the level of osmotic suction. Cryosuction is effective when the temperature in the soil or road materials drops below 0^{o} C (see figure 9 and 10). In low volume roads with materials with high fines content, matric suction explains why these materials have a high bearing capacity when they are dry but lose their strength when they become wet (figure 11). Osmotic suction theory explains, among other things, why chlorides work well as dust binders on gravel road wearing course if the fines content is not high enough. Cryosuction is a force that makes water molecules flow from the surroundings to the frozen fringe under the ice lenses, which as a result grow and cause frost heave in the road or soil surface.

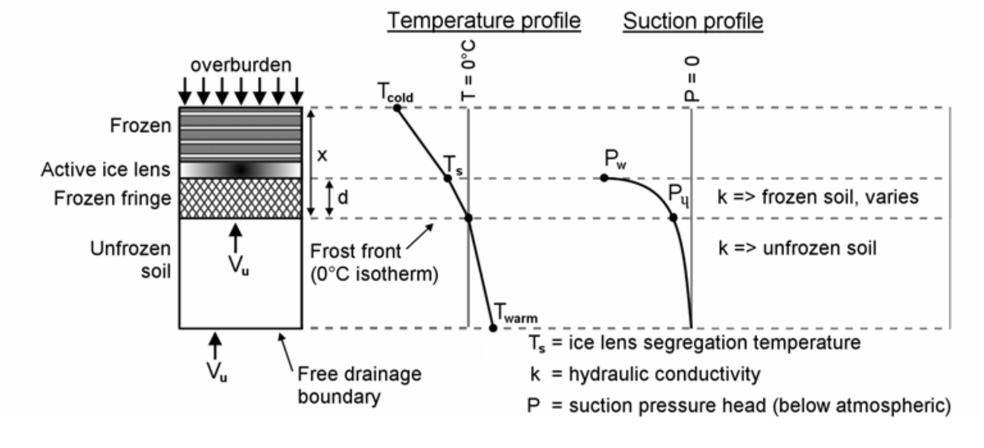

Figure 9. Distribution of temperature and cryosuction during the formation of an ice lens. Figure modified after Mokwa (2004)

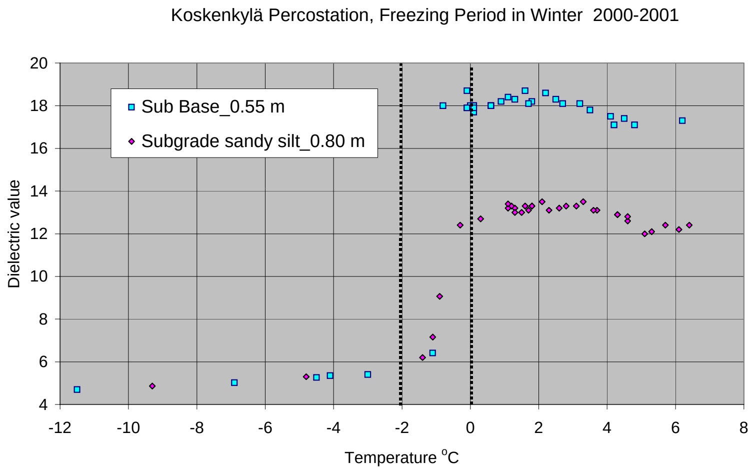

Figure 10. Dielectric values vs. temperature profiles measured at the Koskenkylä Percostation. Unfrozen water is present between 0°C and -2°C (Saarenketo et al. 2002a).

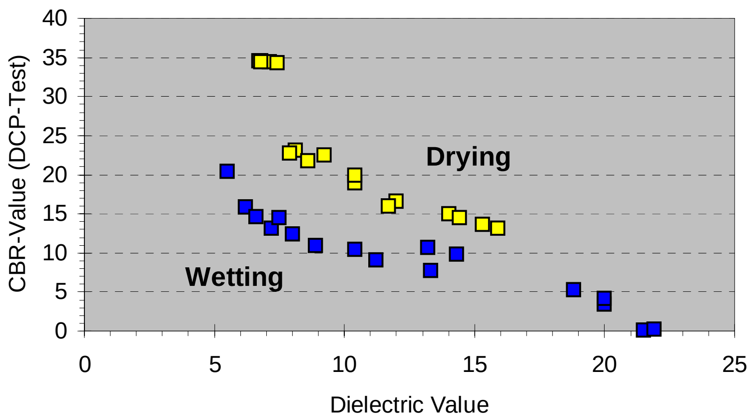

Figure 11. CBR value vs. dielectric value of base course aggregates (after Saarenketo et al. 1996). Dielectric value is a function of the volumetric content of free water. The figure shows the effect of hysteresis (wetting and drying) on the bearing capacity.

3.3 Frost heave

The term frost heave is usually used to explain the effects of the thawing process on the ground or ground supported structures, such as roads, railways, damns, pipelines, house foundations or pipe walls. From a foundation engineering perspective, the most significant aspect of frost heave is the increase in the material volume during freezing. According to Anderson (1989) the conditions for frost heave are: 1) the existence of materials which are susceptible to frost, 2) ground temperatures of < 0°C and 3) the availability of capillaries and ground water.

As described above moisture is the main factor behind bearing capacity problems and road damage on low volume roads. The freeze thaw cycles bring a new aspect to this problem with changing volume of the road structures and presence of excess pore water. Below $0^{o}C$ the presence of unfrozen water is critical to the formation ice lenses, which causes frost heave. According to Kujala (1991) the amount of unfrozen water is by far the most critical factor in the formation of frost heaves. Tice et al. (1978) have pointed out that below the freezing point the amount of unfrozen water will increase if the moisture content is high enough, even in the non-frost susceptible materials. Kujala (1991) further observes that the subgrade susceptibility to frost damage also correlates to the volumetric moisture content, the specific surface area, the cationic exchange capacity and the capillarity. All of these factors can be estimated by measuring the dielectric value and electrical conductivity of the material. On the other hand, the freezing process is controlled by the amount of dissolved salt and mineral weathering products, such as colloids, in the pore water by lowering the amount of free energy and as a result the freezing temperature (Carpenter and Lytton 1977, Kujala 1991, Saarenketo et al. 2002a).

3.4 Water content and strength and deformation properties

A central factor in the development of damage is excess pore water pressure in the road aggregate or soil caused by dynamic axle loads, which decrease the effective stresses between soil particles. Because the ability of the material to resist deformation under a wheel load depends on the effective stresses between soil particles, the increase in pore water pressure leads to an increase in deformation of the material. The greater the load, the greater the degree of permanent deformation will be (Kolisoja et al. 2002).

A more detailed description of moisture content as it relates to bearing capacity is given in the Roadex report, “Drainage on low traffic volume roads” by Berntsen and Saarenketo (2005). A detailed description of the permanent deformation properties of road materials is given in another Roadex II report by Dawson and Kolisoja (2005).

4 Spring thaw weakening classifications

4.1 General

As discussed earlier "spring thaw weakening" and "spring thaw damage" have different meanings. Being a complex topic several classifications systems have been developed primarily based on a) the type of surfacing, b) the time of the thaw weakening, c) the type and severity of spring thaw damage and d) the topography and geology of the of the spring thaw problem section. A more detailed description of these classifications are presented in the sections that follow:

4.2 Spring thaw weakening periods on gravel roads

Spring thaw weakening in gravel roads has been traditionally divided into two periods a) surface weakening and b) structural thaw weakening. Surface weakening of the gravel road can also take place during a rainy autumn but a structural thaw period can only be related to a spring thaw period.

4.2.1 Surface thaw weakening

A surface thaw weakening phase begins when the air temperatures rise above zero and the wearing course starts to thaw and may become plastic. The frost level at this time is only 50 – 100 mm. At this time the bearing capacity of the road is reduced normally only 10-15 % (Saarelainen & Törnqvist 2004), but road users may find driving on the road unpleasant at this time due to a slippery and plastic road surface (figure 12).

There are many factors affecting the location of surface thaw weakening damage including material properties (fines content), cross fall of the wearing course, rainfall and solar radiation. In addition, if the wearing course is very wet when it freezes during the fall, a severe surface thaw weakening can be expected. During recent years in Finland, several roads with surface thaw weakening problems have been surveyed using Ground Penetrating Radar techniques. The results from these surveys have revealed that surface thaw weakening is often concentrated in the sections where wearing course thickness is greater than 150 mm. Figure 13 shows one example of the location of surface thaw damages. Another cause of surface thaw damage has been the excessive use of dust binding chlorides that adsorb too much water (Saarenketo & Vesa 2000). The length of the surface thaw period depends on weather conditions. During a dry and sunny spring this period may only be a few days.

Figure 12. Early phase of surface thaw weakening on a gravel road. The frost level is only 40 – 60 mm from the road surface. (photo: S. Kohonen)

Figure 13. Typical location of surface thaw damage on a hilly area. In the course of basic maintenance graders push wearing course materials from the hilltops to the valley bottoms where wearing course thickness can, over time, increase to 150 – 300 mm. A thick wearing course together with water from the melting snow and vehicles loads causes the road surface to become plastic. (photo: S. Kohonen)

4.2.2 Structural thaw weakening

A structural thaw weakening or deep-weakening (expression by Simonsen et al. 1999) phase starts when the frost thaws deeper in the road structures or in the frost susceptible subgrade soil. The main cause of softening is thawing ice lenses (segregation ice) that produce excess water above them. The volumetric water content above the thawing ice lenses can be much higher than 100 % and the pressure created by overburden as well as heavy vehicles causes hydrostatic pressure which forces water to flow up and to the side. In many cases, the ditches are also filled with water at that time so the structure is only able to dry through evaporation. If the water permeability of the subgrade is low then moraines, silts and clays can become plastic and they can flow either up to the road centre between the wheelpaths (figure 14) or beside the road (figure 15). This phase, also named the sublayer breakthrough, occurs mainly in late spring when the frost level is deep or it has totally thawed.

Figure 14. Structural spring thaw damage on road 9613 in Kemijärvi, Finland in 27.5.2003. The subgrade soil is moraine. Notice the widening of the damaged area. Photo:Tarmo Posti.

Figure 15. Plastic silt squeezing from the road shoulders during the structural thaw period at the Kemijärvi Percostation site in 03.06.2003.

4.3 Spring thaw on paved roads

Compared to gravel roads spring thaw weakening cannot be visually classified into different time phases with paved roads. However some general trends during the weakening phases and distress types appearing during these phases can be observed.

Figure 16. Water breaking through the asphalt from the thawing base course during early spring 2004 in Finnish Lapland.

The first critical periods for paved roads occur around the same time as surface thaw weakening in gravel roads and is very critical especially for roads with surface dressing pavement with frost susceptible and/or wet base course or with an old gravel road wearing course under the pavement. When the sun heats the pavement the surface part of the unbound material also thaws. This thawing causes a water saturated layer between the pavement and a frozen and impermeable base course. Dynamic loads cause high hydrostatic pressure and if the pavement is not porous or stiff enough, it will result in severe cracking, potholing or deformations (Figures 16 and 17).

Figure 17. Spring thaw damage on a road with surface dressing in Northern-Karelia in Finland. Photo Martti Leppänen.

Later during the spring thaw, the problems are mainly related to roads with frost susceptible and weak subgrades (figure 18). A frost susceptible layer deeper in the pavement structure can also cause pavement deformation as results, presented later in this report, from the Koskenkylä Percostation in Rovaniemi Finland will show. The rutting during this phase is much wider and pavement cracking occurs only in the most severe cases. Spring thaw weakening damage can also be found in road sections with poorly performing drainage or differential frost heave.

Figure 18. Spring thaw weakening damage on a paved road in Senja, Norway.

4.4 Spring thaw weakening classification by subgrade soil and topography

Classification of spring thaw damage can also be based on the subgrade type and topography of the damaged section. Based on the surveys conducted in the Vaasa Region of Finland Saarenketo et al. (2002b) have classified spring thaw damages according to the subgrade type and whether the road is located in a flat area, valley bottom or transversely sloping ground. The following classification system has been used successfully in Finland to classify the most typical spring thaw damages and has been found to be useful in selecting the optimum repair technique on gravel roads. However the same classification system can also be used on paved roads:

a) Moraine subgrade in a low lying and wet valley
b) Moraine subgrade soil in wet and transversely sloping ground
c) Frost susceptible morainic hummock
d) Peat sites
e) Bedrock related damages
f) Silt or clay subgrade in a flat and even area
g) Silt or clay subgrade in a low lying and wet valley
h) Silt or clay subgrade in transversely sloping ground
i) Other sites

In addition to this classification classes A-I divided into three (1-3) subclasses depending the severity of the spring thaw damages. The subclasses are:

1. Mild problems, where spring thaw problems are not severe and do not occur annually
2. Medium problems, where light or medium severe spring thaw problems are found almost every spring
3. Severe problems, where medium or severe structural spring thaw problems have been monitored annually

5 Load restriction policies in cold climate areas

5.1 General

Seasonal changes are one of the biggest concerns in the management of low volume roads in cold climate areas. Weight restrictions are used in nearly all areas, where the road structure is frozen for a part of the year. During the year's most critical seasons, when the road's bearing capacity is at its weakest the road structure needs protection. Such areas are typically found in Scandinavia, Canada and the Northern U.S.A. Scotland also uses weight restrictions. Norway is an exception, since 1995 temporary weight restrictions have not been used and instead permanent weight restrictions are used on the weak roads.

However, a common issue for these countries is that the transportation industry, especially operations related to forestry and fishing has become an important factor. Therefore road maintainers are under more pressure to lower the overall number and duration of weight restrictions. In addition, greater axle loads are being allowed during the winter.

The following sections present the basic weight restriction policies of Sweden, Finland, Norway, Scotland, U.S.A and Canada.

5.2 Sweden

Sweden uses both permanent and temporary restrictions. For permanent weight restrictions Sweden rates roads into classes BK1, BK2 and BK3. BK1 permits the use of a maximum 60 tons total weight. For BK2 and BK3, the total load permitted is 51,4 tons but for BK2, the driving axles' and other single axles greatest load allowed is 10 tons while the corresponding value for BK3 is 8 tons (Roadex 2001). Currently there are 5565 km of BK2 roads and 1148 km of BK3 roads in Sweden (*www.vv.se/vbd/webb-sidor/Barighetsklass.gtm*).
Permanent weight restrictions are used mainly on roads with weak bridges but also on very weak paved and gravel roads (figure 19). On the other hand, BK2 and BK3 class roads have been changed to BK1 during winter (Roadex 2001).

Figure 19. BK 2 road in Övertorneå Sweden.

In Sweden during the spring thaw period, about 12 000 – 15 000 km of road are closed to heavy traffic. Restrictions are in place, on the average, from 40 – 50 days, normally from the beginning of April to the end of May. In the Region Norr area, about 60% of the region's gravel roads have had annual weight restrictions. Approximately 73% of the weight restricted roads have a gravel wearing course and about 27% are paved. Region Mitt has started to apply a new weight restriction policy with exemptions and today the region only has about 1800 km of road with spring load restrictions annually (Roadex 2001, Vägverket Region Norr 2002, Region Dalarna 2003).

Since 1995 and 1996, Region Mitt and Region Norr have applied a similar policy regarding temporary weight restrictions. It states that weight restrictions should not be used on national and regional roads. Local roads are not allowed to be restricted if they are classified as being strategically important. Weight restrictions are set by the administrative organization on the basis of field evaluations. Normally a maximum total load of 4 tons or 12 tons is used when roads are restricted (Vägverket 1995, Roadex 2001).

New proposal 2000

In 2000, a proposal was made in Sweden that a new nationally harmonized weight restriction policy, based on the policies previously used in Region Mitt and Region Norr along with some additional features from weight restriction policies of other road regions, be implemented. The goal of this new policy was to use weight restrictions only on certain parts of the road network, where the need to use heavy transports for local livelihood and industries is minor. On a restricted road network exemptions will be given to essential heavy traffic such as school transports or food supply. The local maintenance crews can also give exemptions to other heavy traffic. The goal of this harmonisation was to start to apply a policy where optimal measures can be taken at the appropriate time and in such a way that road users would receive adequate information regarding restrictions and that they would have the possibility to react to a decision. (Förslag 2000)

According to this proposal, weight restrictions can only be applied to certain road sections that have been listed prior to any restrictions and meet the standards for load restrictions. In an exceptional case, such as exceptional weather conditions or unforeseen traffic loads, restrictions can be used on roads that have not necessarily met the aforementioned criteria. On paved roads, weight restrictions can be imposed when more than 1% of the road length shows distress that will result in rutting or in other way cause harm to the traffic. On paved roads with surface dressing and old oil gravel roads weight restrictions are implemented when distress appear on more than 3% of the road length. With unpaved gravel roads restriction can be considered when > 3% of the road length show signs of distress. Weight restrictions are removed as soon as they are no longer needed. Weight restrictions are marked with appropriate traffic signs. The amount of restriction is either 4 or 12 tons. (Förslag 2000).

Weight restrictions are not applied to emergency vehicles, school transports, buses on standard routes, animal-, general supply-, feed-, mail deliveries, public sanitation nor road maintenance vehicles. Possible exceptions are granted by the road authority, which can also delegate this responsibility to a maintenance contractor. Temporary permission can be granted to vehicles that do not cause road distress or any distress that they may cause can be handled through basic road maintenance. In special cases, temporary transport permission can be granted if the transport contractor pays for the road's repair. Permission can be removed, if necessary, due to changes in conditions or if more road distress occurs than was originally estimated. (Förslag 2000).

Currently, the new weight restriction policy, proposed in 2000, has not officially been put into practice, yet it has been put into practice in most Swedish road regions. The role of the Swedish Road Administration has been, according to road district personnel, quite passive and the road districts have practically been independently responsible for their area's weight restriction policy.

5.3 Finland

All of the public roads in Finland allow a maximum of 60 tons total weight, which requires a minimum 7 axle truck. The highest allowed bogie load depends on the number of axles and axle spacing and varies between 100 and 240 kN. Permanent restrictions have been used only on few roads with weak bridges (Roadex 2001). Super single tyres are allowed with a recommended maximum tire pressure of 850 kPa.

Spring thaw problems in Finland have been treated in two ways: 1) load restrictions have been implemented in roads with potential or previously recorded spring thaw damage and 2) the sections with the worst spring thaw damage have been repaired. Annually Finnra has used about 12 M€ for repairing spring thaw problem sections (Saarenketo & Perälä 2003).

In the late 1990´s and early 2000´s, the regional road districts in Finland have used different kinds of spring load restriction policies, which could be different even within a singular road region. Some road regions have totally given up the use of load restrictions and focused on repairing the damages and on co-operation with industries using heavy transport vehicles. These divergent policies have created confusion among road transporters and local road authorities, which is why in 2003 as a part of strategic research project S14 Finnra decided to develop and test a new harmonized load restriction practise in the whole country. The goals for the new load restrictions policy (Painorajoitusohje 2004), which was tested in spring 2004, are to:

- Maintain the traffic serviceability of roads with poor bearing capacity during the spring thaw weakening periods at as high a level as possible
- Minimize the spring thaw weakening problems for the road users and important transports
- Ensure that road maintenance costs will not rise unnecessarily on roads suffering from spring thaw problems
- Ensure that all maintenance contractors are treated equally within the road condition management policies for spring thaw problem roads

The process used in the new spring load restriction policy is described in figure 20. The first thing in this evaluation process is to evaluate the importance of the road to the transportation industry and local livelihood and then, based on this evaluation, roads are classified into four categories, where class A roads are considered to be so important that weight restrictions cannot be used on these roads or roads that do not have notable spring thaw weakening problems. Classes B, C and D are divided based on the severity of structural thaw weakening damages previously inventoried on these roads (figure 20).

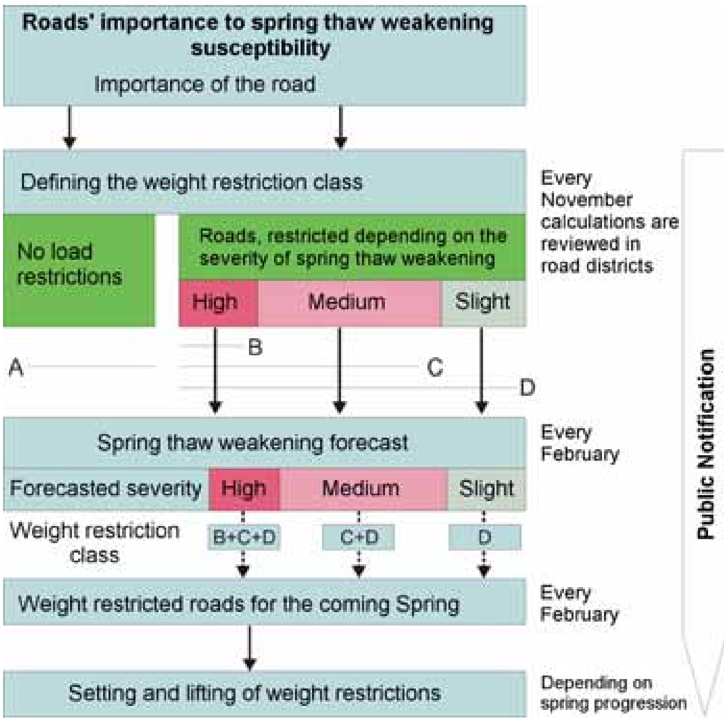

Figure 20. New weight restriction procedure used in Finland in 2004.

Every February a spring thaw weakening forecast will be made based on the model developed by researchers at the University of Oulu (Ryynänen et al. 2003). The so called “autumn model” used in this forecast is based on the statistical analysis of different factors affecting the severity of previously recorded structural thaw weakening damage on gravel roads in Finland from 1998 to 2003. The most significant factors are the elapsed time for the structure to freeze, ground water level and the median length of weakened road in each area. The forecast for thaw weakening is only applicable to an area and it cannot be used to forecast the extent of structural thaw weakening for one particular road.

Based on the spring thaw weakening forecast for each area, it will be decided if weight restrictions are to be used only on class D roads or, if the forecast predicts more severe spring thaw weakening, then the class B and C roads will need to have restrictions too. After decisions have been reached the regional road administrations inform transporters of the restricted roads.

Load restrictions can be applied to both gravel roads and weak paved roads. The screening method for selecting road sections that require load restrictions follows the same principles as in Sweden but instead of visual evaluation, case by case, the screening is based on Finnra’s spring thaw damage inventory and pavement distress databases. The flow chart for determining the need for the weight restrictions on gravel roads is presented in figure 21.

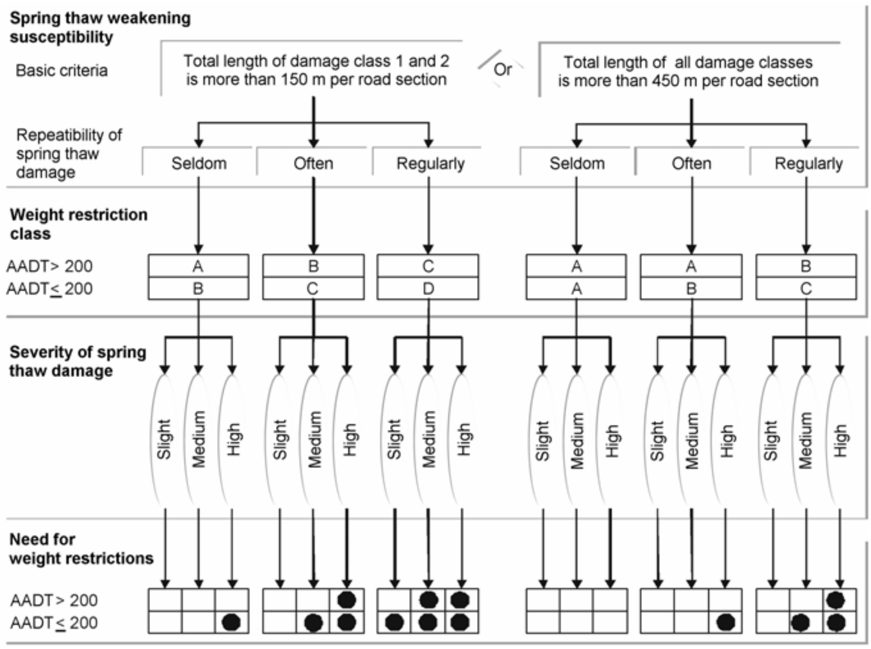

Figure 21. A flow chart used to determine the need for weight restrictions on gravel roads in Finland according to Finnra’s new weight restriction policy of 2004. First the total length of spring thaw damaged road during the last 5 years is calculated. The limits for further actions are 150 m and 450 m per road section. If the length exceeds these limits then the repeatability of the damages are divided into three classes and further classified according to traffic volume into two classes. Finally the need for weight restrictions is evaluated based on the forecast of the severity of the damage and traffic volume.

In Finland, load restrictions do not apply to vital heavy transports, such as scheduled bus traffic, school transportation, dairy or meat processing transportation, transportation of food supplies, or transportation related to energy management (i.e. peat for central heating) or road maintenance vehicles. Transportation of other commodities such as timber, aggregates, construction supplies, fertilizers and irregular fuel transport require exemptions.

The new load restriction policy also uses the same Swedish maximum total weights of 12 tons and 4 tons.

The experiences of the new load restriction policies from the first spring in 2004 were mainly positive, even though, thanks to a favourable spring in 2004, there were hardly any spring thaw weakening problems in many of the districts. In 2005 changes to the load restriction policies will only be made to the screening methodology for roads with surface dressing. The need for load restrictions on these roads will no longer be based solely on the visual distress evaluation results and these roads do not need to have high amount of distress in order to have load restrictions applied.

5.4 Norway

Compared to Finland and Sweden, Norway has implemented a different policy where temporary load restrictions are not used although many Troms County roads do have permanent load restrictions. Norwegian roads have been classified into four utilization groups depending on the permitted axle loads and total weights (Bk 10, BkT 8, Bk 8, Bk 6) (figure 22). Maximum total weight for a vehicle in Norway is 50 tons. About 90 % of the national and county roads allow this total weight and about 9 % permit 40 tons total weight. Less than 1 % has 28 or 32 ton total weight limits (Roadex 2001).

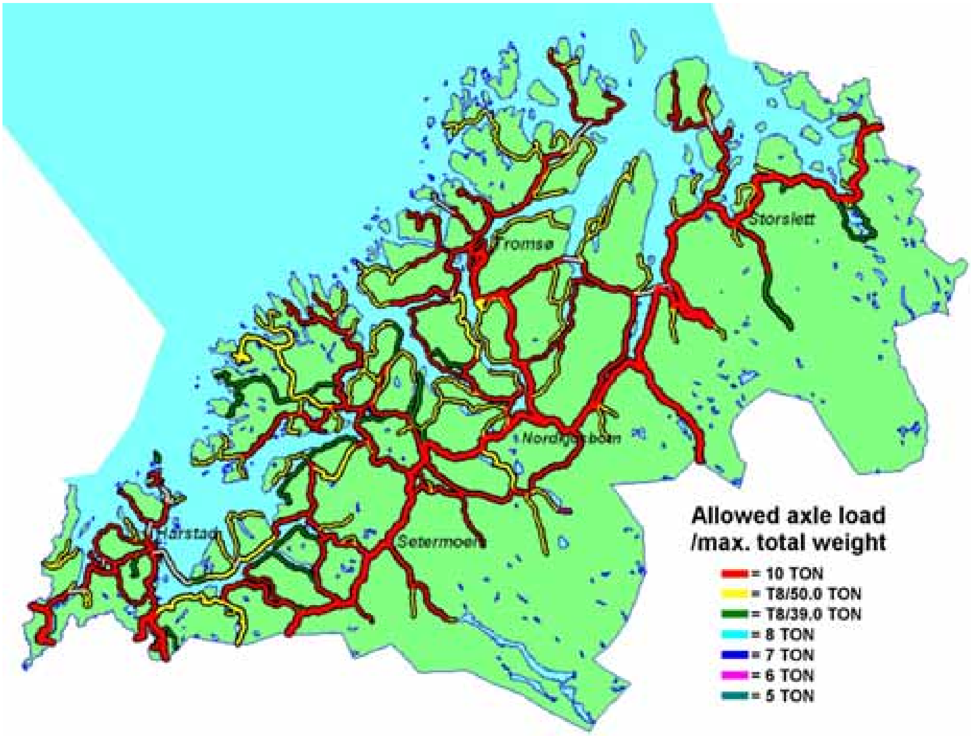

Figure 22. Maximum allowed axle loads and total weight in Region Troms in Norway (Roadex 2001).

In 1994, 50% of the main roads and 96% of the local roads in Northern Norway still had temporary weight restrictions. During the spring of 1994, 50% of the entire country's road network was weight restricted. Before 1995 all public roads were classified according to the highest total load allowed. The classification was based on the bearing capacity of bridges and each year Vegliste published a guide listing all of the roads and presenting the highest axle weight, total weight, vehicle width and height allowed for each road (Isotalo 1993, Roadex 2001).

In 1994, the Norwegian Public Road Administration, through the Norwegian Road research Laboratory (NRRL), completed a four-year research program entitled “Better utilization of the bearing capacity of the roads” (BUAB). It focused on the financial advantages of removing seasonal load restrictions. According to the research, removing springtime weight restrictions would save 330 million NKr (~41 M€) for the road users but it would also raise the maintenance costs by 145 million NKr (~18 M€) (figure 23). The research further estimated that if the service level of the road network were to remain at its current level, the extra costs for road maintenance would have been about 210 million NKr (~ 26 M€). On this basis, spring load weight restrictions were no longer applied and road districts were appointed extra funds for maintenance. For example Region Troms annually received, from 1995 – 1998, about 10 mNOK (~1,2 M€) of so called BUAB funds for spring thaw damage repairs. However since 1998 these extra funds were no longer allocated to the NRA budgets (Roadex 2001, Refsdal et al. 2004).

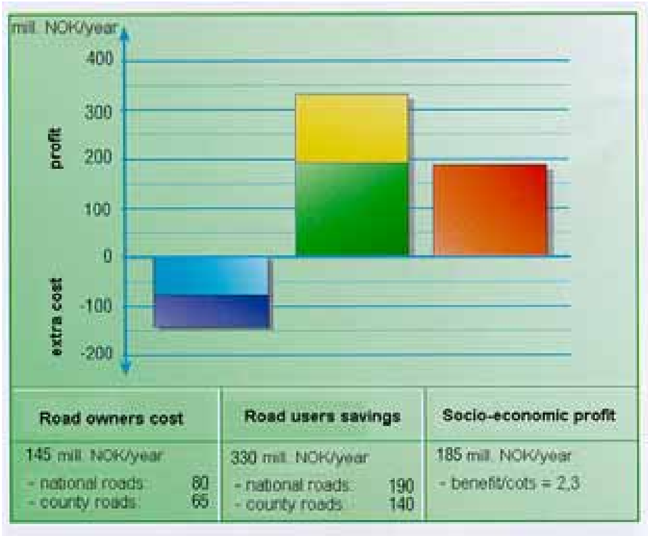

Figure 23. Road owner costs, road users savings and socio-economic benefits of the removal of temporary weight restrictions on public road in Norway based on calculations made in BUAB project 1994.

Since removing the spring load restrictions in 1994 the condition of paved roads has been monitored using profilometers and, according to Refsdal et al. 2004, there have been no indications that road surfacing serviceability has decreased. The reasons why it has been able to maintain the serviceability at 1994 during the period with reduced budgets have been evaluated to be (Refsdal et al. 2004):

- The road users have not fully utilized the new possibilities of higher axle loads
- There has been a slow but steady increase in the surfacing service life from 1985 to 2002 from approximately 10 to 15 years for national roads and from 13 to 18 years for county roads
- There use of studded tires during winter has decreased
- There has been a general improvement in asphalt techniques and procedures, like thin surfacing

5.5 Scotland

In Scotland the regulations concerning traffic loading are complicated, with vehicle configuration playing a large part in the allowable axle loads. In general, the maximum allowable axle weight is 9.5 tonnes, but when the axle is a driving axle, this can be increased to 10.5 or 11.5 tonnes, depending on the arrangement of tires (Roadex 2000).

The maximum allowable vehicle weight is 41 tonnes with a minimum of six axles, (with driving axle restricted to 10.5 tonnes and all other axles no greater than 8.5 tonnes). One exception is for vehicles involved in combined transport operations (rail/road), where the maximum allowable weight is 44 tonnes. Such a vehicle must be coming from, or going to, a railhead. Some roads are ‘weight restricted’ simply because the road width and alignment is unsuitable for all but the smaller vehicles (Figure 24).

Single tires (also known as 'super single' tires) are allowed but must have a road contact width greater than 300mm. For vehicles above 38 tons road friendly suspension and twin tires (on all axles except the drive axle) must be used (EU Directive 85/3). The tire manufacturers dictate tire pressures for their tires. For normal tires the maximum pressure can be up to 9 bar. For special tires, i.e. for non-standard use, the pressures can be up to 9.9 bar.

Figure 24. Road B869 Lochinver-Stoer-Drumbeg-Kylesku is a typical road subject to load restrictions in the Scottish Highlands. It is a 3m wide single track route with passing places that passes through some of the most rugged rocky scenery in the western Highlands. Its tortuous alignment makes it unsuitable for coaches or heavy vehicles over 24.5 tons.

Bridges with a clearance of less than 5.5metres are signed with the allowable height. The Department of Transport (Central Government) gives authorisations for transportations with loads > 150t, width > 6.1metres or length > 27.4 metres (Roadex 2000).

Temporary restrictions in the Highlands are not made due to spring thaw conditions, as frost thaw weakening is not usually significant. However where a road is subjected to increased use of heavy trucks and is deteriorating as a result, restrictions on use can be imposed to prevent further damage. Such preventative weight restrictions are typically applied to single track roads where timber transportation takes place, or on road sections with weak bridges or retaining walls. Emergency restrictions can be made for 6 weeks and temporary restrictions for 18 months; normally such restrictions become permanent unless mitigating measures are taken.

The region is divided into eight 'areas', and in each of those areas the Area Roads and Transport Manager decides on the application of road restrictions. Any proposal requires the approval of the Roads and Transport Committee before legal measures can be taken. Part of making the order is publicizing the proposal and providing a period for objections. Consultation with the Freight Transport Association, Load Haulage Association and other bodies is carried out when a road order is proposed. Should objections not be resolved then a Reporter selected by the Scottish Office would decide whether the Order should be made. Restrictions are often applied to bridges even if only the road requires it, as the public can more easily accept bridge restrictions than road restrictions.

5.6 U.S.A. and Canada

In the U.S.A., sixteen states reported using weight restrictions annually and four use them when the conditions demand. Of all the states using weight restrictions all are using them on asphalt, ten are applying them on roads with surface dressing and only five implement restrictions on gravel roads. The reason that only five departments implement restrictions on gravel roads is that they are not usually under a state's department of transportation's control but are managed by cities, counties or private organizations, which are then also responsible for setting the weight restrictions on them (Kestler et al. 2000)

In the provinces of Western Canada's prairie area and in the Northern parts of the U.S.A., many complicated and often overlapping regulations are in use concerning greatest allowed total weights, spring weight restrictions and winter premiums (raised axle loads). The regulations change according to the need, size and the duration of the weight restrictions. (MacLeod et al. 2002).

In Western Canada and the Northern USA weight restrictions can differ from normal regulations up to 7 months of the year, since the winter's raised axle loads can be permitted from the start of December and spring weight restrictions can be removed as late as the 30th of June. This shows that adjusting the duration and level of weight restrictions plays an important role in the preservation of the road infrastructure as well as creating an efficient transportation policy from a economic perspective. (MacLeod et al. 2002).

When selecting the weight restricted road sections, the Washington State Department of Transportation recommends evaluating the changes between the summer and the spring FWD deflections values, the pavement thickness, the quality of the subgrade soil as well as taking into consideration the local maintenance crew's knowledge of drainage and bearing capacity properties and the current condition of the road. According to the report by Rutherford et al. 1985, weight restrictions should be used on road sections where springtime deflection values are 45-50% greater than summer values. Special cases can, however, change this limit. (Mahoney and Jackson 1990).

Other candidates for weight restrictions are roads with pavement thickness of 50 mm or less, roads that are located in areas with a freeze-index (FI) greater than 220 ºC –days (400 ºF days) and areas where frost is assumed to reach a depth of 50 cm or deeper. Roads with a silt or clay subgrade are also candidates. Local knowledge of drainage and bearing capacity properties should also be considered. This way, drainage of the lateral drain, depth to groundwater, snowdrift accumulation and ploughing policy are taken into consideration. When alligator cracking and rutting appear in spring, weight restrictions are needed especially if strengthening measures are not possible. Local knowledge combined with road condition survey data (for example pavement deflection measurements) is considered to be a qualified method for choosing weight restriction targets. (Mahoney and Jackson 1990)

5.7 Load restriction timing techniques

Selecting the date for weight restriction has a significant impact on the lifetime of the road. Research done in Minnesota, U.S.A., shows that weight restriction set a week too late can shorten the lifetime of the road by 4 - 8%. On the other hand, if higher winter axle load premiums are removed a week too late, this can shorten the lifetime 5 - 12%. (MacLeod et al. 2002).

A number of ways are used to make decisions on the timing of load restrictions. Rarely is the decision based on measured data since usually the road managers resources are insufficient for extensive measurements. The selection of a date is usually based on road condition surveillance and knowledge from previous years, although the pressure to develop new prediction methods has clearly increased. In the United States and some parts of Canada, road authorities are using a model based on temperature index (TI) and frost depth information collected from various sources.

In Sweden, traditionally load restrictions have been implemented immediately after surface thaw weakening has begun. Decisions regarding restrictions are made based on visual evaluation of the road surface and the local engineer's observations of road performance in the area. No distinct rules apply as to when load restrictions should be imposed or lifted (Roadex 2001)

Finland also did not have clear rules for the timing of weight restrictions until the new load restriction policy came into effect in 2004. The new policy recommends that weight restrictions be imposed when the frost has thawed to a depth of 0.15 m on gravel roads. Weight restrictions can be removed when the frost has thawed to a depth of 0.8 m and/or the topmost part of the road has enough dry layers the carry the loads. Load restrictions can also be removed when frost heave is less than 80 mm in the road centre and if the road does not have any additional indications of spring thaw weakening damage (Painorajoitusohje 2004).

When spring load restrictions were still used in Norway, the restrictions were imposed when the thaw depth was 0.1 – 0.2 m. Restrictions were removed depending on the maximum frost depth and the ratio between the permitted axle load during the spring thaw and during the summer. If the axle load ratio was 0.8 and if the frost depth was 1.5 m, weight restrictions were removed two weeks after the thaw depth was 1.25 m. Normally the load restrictions were applied for 4 – 8 weeks (Roadex 2001).

5.8 Controlling and monitoring axle loads and total weights

There are also major differences in controlling total loads and total weights. Table 2 presents a summary of how weight restrictions are controlled in the Roadex road regions.

Table 2. Summary of weigh restriction control systems (modified from Saarenketo and Saari 2000).

	Finland	Norway	Scotland	Sweden
Control enforcing authority	Police	Road Region / Traffic dept.	Police	Police on assignment from road admin.
Primary object of control	Axle load	Axle load, wheel load	Vehicle length and width, plated vehicle weight	Axle load
Control equipment	Portable scales	Stationary / transportable scales	Weighbridge, transportable scales	Stationary / portable scales
Sanctions	Stepped progressive penalty fees	Penalty fees, unloading, revocation of licence	Penalty fees, unloading, revocation of operator licence	Progressive penalty fees (both driver and the haulage co.)

In Sweden the police monitor axle loads as a special part of traffic surveillance. The Road Administration, who also pays for traffic surveillance, decides on the level of monitoring. Other roads users often contact the Road Administration if they suspect overloading. The Road Administration then contacts the police if a inspection is to be made. A progressive fine is used as an overloading penalty. Both the driver and the haulage company are subject to the penalty.

The police have 4 stationary and 3-4 portable weigh scales for monitoring vehicle loads. There is also an on-going research and development project to test different types of WIM (weigh-in-motion) measuring devices in the cold climate. These devices have been installed in the pavement on the national road E4 outside Luleå, but they are only used to indicate that there might be an overload. In order to prosecute, the vehicle must be weighed on a stationary or portable scale.

In Finland the police and local area supervisors control load restrictions, but only the police can impose fines. Area supervisors are only allowed to contact the police when they observe an overloaded transport. Fines are used as penalties for overloading and the amount of the fine is stepped according to the amount of overload. The police monitor axle loads as a part of traffic surveillance. Axle loads are measured using portable scales. Finnra also conducts axle load measurement to study loads. The area supervisor’s duty is to make observations on load effects on the road structures. An inventory of road damage is made annually. The results of these inventories are a basis for rehabilitation measures.

The Traffic Department of the Region Nord of the Norwegian Road Administration is also responsible for monitoring axle loads and total weight of the vehicles via district offices. They possess six stationary scales for measuring triple axles up to 30 tons as well as transportable scales for measuring wheel loads up to 10 tons. These scales are tested in the same way as scales used for trading. There are different kinds of sanctions when a vehicle has been found to be overloaded: the haulage company has to pay a fine (there are fines set for both axle loads and the total weight of the vehicle; the highest of these two will be used), the vehicle will have to be unloaded, the driver will be reported to the police and penalized if the overload is extreme, the driver can also lose his licence to drive, the haulage company can lose their permit to do transportation and the vehicle can be barred from further use in transportation.

In Scotland only the police can enforce weight restrictions, but for enforcement to succeed the vehicle must pass an authorised weighbridge on its intended journey. Unfortunately there are insufficient numbers of these weighbridges in the area to allow effective control of vehicle weights. There are currently no axle restrictions in the Highland Council's area primarily because they are difficult to monitor. It is more effective to restrict the length and width of vehicles (which effectively restricts the heavier vehicles) as this is easier to enforce. A local user of timber has assisted the Roads department by only paying for timber up to the plated weight, any excess being obtained free.

5.9 Spring thaw condition monitoring techniques

Unfortunately, the formation and degree of spring thaw damage inflicted on the road structure varies from year to year and, as such, monitoring techniques for spring thaw weakening are needed. Canadian C-SHRP report 21 (2002) reported several procedures used to time the imposition of weight restrictions. Direct methods include the use of frost tubes or deflection testing, while indirect methods include the use of historical databases, weather forecasts, prediction models or expert judgements.

In Sweden the local road engineers monitor road condition but there are no systematic approaches to collecting the data.

Since 1996, Finland has been using a systematic approach to monitor spring thaw damage on gravel roads. A visual evaluation of spring thaw damage on a gravel road is used to divide road sections into 3 classes based on the severity of the damage. In 2004, a fourth was added to indicate very slight spring thaw damage. Finnra has published a guidebook with written explanations to help field crews with classification of the damage. These classes are as follows:

Class 1 (figure 25): Driver must almost stop the vehicle to evaluate if passing this section is possible. In this class the driver must carefully select a route to pass the damaged area because the vehicle bottom could come into contact with damaged road surface. The road structures have been severely mixed.

Class 2 (figure 26): Driver must lower his speed appreciably when passing the damaged section. Road surface has squeeze outs and plastic soft spots that force the driver to select a driving path.

Figure 25. Example of Finnish spring thaw damage class 1 on gravel road (Painorajoitusohje 2004).

Class 3 (figure 27): The road structure, for the most part, has adequate bearing capacity, but drivers need to reduce their speed slightly due to deformations, collapses in the road shoulders and slight softening of the road structures.

This classification is done each spring on the gravel roads known to have spring thaw damage. A certified crew equipped with a GPS positioning system does the survey from a moving vehicle. The results have proven to be quite reliable and they have provided the Finnish road administration with an excellent perspective on the total length and severity of spring thaw damage in the country. Table 3, based on these databases, presents the changes in total length of spring thaw structural damage from 1998 – 2003. Figure 28 present the area distribution of the damage in Finland. It shows that the spring thaw structural problems are worst in the timber industry area in Central Finland.

In addition to that, these spring thaw damage databases are now used as key background information in repair and strengthening design of the damaged road structures.

Figure 26. Example of Finnish spring thaw damage class 2 on a gravel road . (Painorajoitusohje 2004)

Figure 27. Example of Finnish spring thaw structural damage class 3 on a gravel road. (Painorajoitusohje 2004)

Table 3. Total length of monitored spring thaw damage on gravel roads in Finland 1998 – 2003 (Ryynänen et al 2003)

Year	1998	1999	2000	2001	2002	2003
(km)	1193	876	949	1000	464	252

Finland is also the only country in the Roadex area that has a systematic approach in monitoring pavement distress on paved roads. This distress mapping is repeated at 3 year intervals on roads with known distress problems. Most of distresses are surveyed and measured in square meters and the results are stored as 100 metre values in the road condition database (KURRE). Finnra also calculates a summary index, using the individual distress values, called the Sum of Pavement Distress. This value is used to monitor the trend of the pavement surface condition. The Finnish Road Administration has tested the amount of alligator cracking as one indicator of the need to impose weight restrictions but in 2005 the key parameter was changed to rut depth (ridge) measured using profilometer.

Another good indicator of spring thaw weakening damage is the rut depth and the rate at which it increases in paved roads.

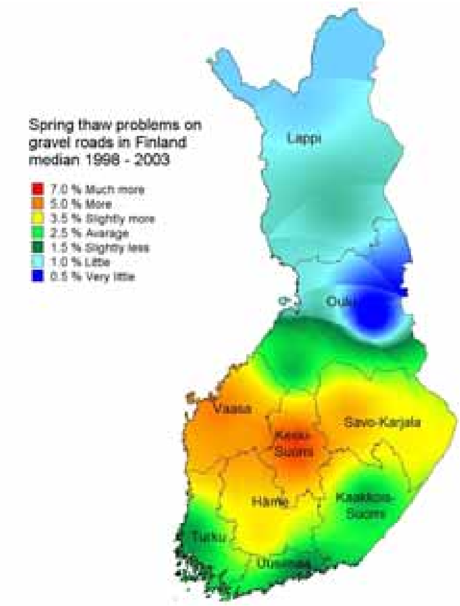

Figure 28. The relative distribution of spring thaw damage on gravel roads in Finland (Ryynänen et al. 2003)

6 Roadex II test sites

6.1 General

The goal for the field tests in Roadex II project was, through the use of modern survey and monitoring techniques, to collect and analyse data from these sites which are representative of typical spring thaw or freeze-thaw cycle problems.

Figure 29 presents the location of these sites in Scotland, Sweden and Finland. Two of the sites were paved roads (Garvault, Koskenkylä) and three gravel roads (Kuorevesi, Ängesby, Kemijärvi). A more detailed description of the test sites is given in the sections that follow.

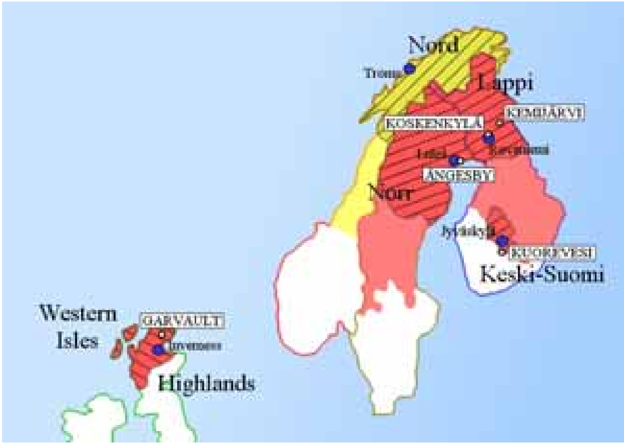

Figure 29. Location of Roadex II test site

6.2 Koskenkylä, Finland

The Koskenkylä test site in the municipality of Rovaniemi in Finnish Lapland has been monitored since 1999 when the first Percostation was installed on road 9421. This road was reconstructed in the early 1980's and since then part of the road has been re-surfaced. The traffic volume (AADT) on the road is 407 of which 45 are heavy transport vehicles. The number of heavy transport vehicles during the spring and summer seasons is significantly greater, since Jokkavaara, Rovaniemi's largest sand and gravel pit area, is situated only a few kilometres from the station. Due to the transportation of aggregates from Jokkavaara, the vehicle loads on the left lane of the road, leading to Rovaniemi (figure 30), is noticeably heavier than on the right hand lane. This is also evident in that the left lane has deeper ruts than the right lane. According to the results of surveys conducted over the years on this site, the main source of the bearing capacity problems at the site is surface material, from the old gravel road, which was left in the road structure as a sub base when the new layers were constructed over top. Table 4 presents an overview of the road structure and subgrade in the Percostation area.

Figure 30. Koskenkylä Percostation site near Rovaniemi. The right lane (in this photo, left lane in survey) lead towards Rovaniemi. FWD points are marked with white paint.

Table 4. Layers of the pavement structure at the Koskenkylä Percostation.

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Layer	Depth (mm)	Fines (%)	Type of material
Surfacing	0 – 80		Asphalt concrete
Base course	80 – 450	4 – 7	Base made of two layers of crushed rock aggregate 0- 30 and 0 – 55 mm
Sub-base course	450 – 650	18 – 20	Gravel with high fines content (the old road structure)
Subgrade I	650 – 900	70 – 80	Silt
Subgrade II	900 – 1400	11 – 50	Layered silty sand
Subgrade III	1400 – 2500	4 – 10	Sand

More detailed information about the Koskenkylä test site, its materials and earlier research results are given in the papers by (Saarenketo et al. 2002a, Vuorimies et al. 2001).

6.3 Kemijärvi, Finland

The Kemijärvi Percostation is located on road 19783 in the village of Tohmo close to the city of Kemijärvi. According to the Finnra Spring Thaw Damage Data Base, this section has repeatedly had severe or medium severe spring thaw damage since 1996. This road section also suffers, in many places, from severe differential frost heave problems (figure 31). The traffic is mainly commuter traffic, AADT is 373 and the amount of heavy traffic is 18. Heavy vehicles are mainly linked to farming but occasionally timber trucks also use this route.

Figure 31. Uneven frost heave bump around a culvert on road 19783 in Kemijärvi. The average frost heave on both sides of the culvert, which has a good foundation and is not heaving, is 40 – 50 cm.

The Percostation was installed in this road in October 2002. At the Percostation site the road, built on a slight embankment, crosses a field area with silty subgrade. Figure 32 presents a photo and a GPR profile of a cross section measured at the Percostation site. The GPR showed that the structure thickness has major changes in the cross section of the road. In the road centre, under the wheelpaths, the structure thickness is about 0.7 m, while on the road shoulder the total thickness is only 0.15 – 0.25 m. The GPR profiles show that the structure's layers have mixed with the subgrade in some areas. The Figure also shows the location of the Percostation probes in the profile. A summary of the materials is presented in table 5.

Table 5. Layers of the pavement structure at the Kemijärvi Percostation.

Layer	Depth (mm)	Type of material
Wearing course	0 – 200	Crushed rock aggregate 0 – 16 mm
Road Structures	… – 450	Crushed gravel, gravel 0 – 35…55 mm
Embankment	… – 750	Glacial moraine, gravel
Subgrade		Silt

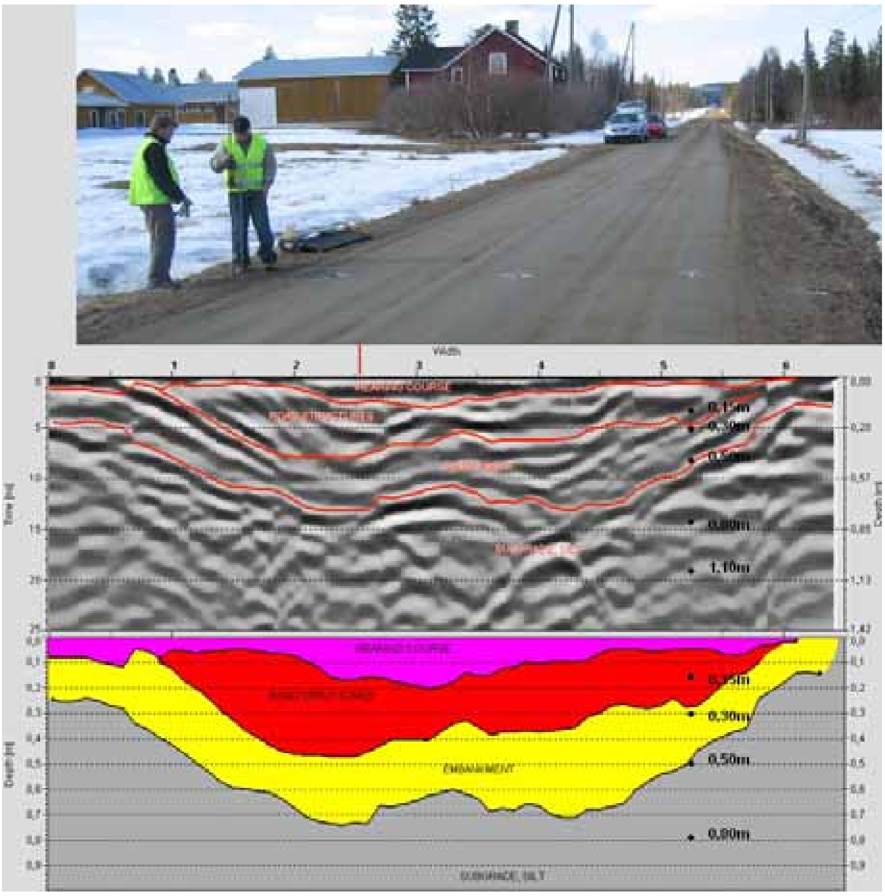

Figure 32. Kemijärvi test site, GPR cross section profile and its interpretation showing the road structure and the location of the Percostation probes. The road width at the test site is 6.4 m. Trucks with full loads are mainly using the left side of the road.

6.4 Kuorevesi, Finland

The Kuorevesi Percostation test site is located in the municipality of Kuorevesi in the Keski-Suomi Road Region. Road 3421, road section 3, where the station was installed has a traffic volume of 298 (AADT) with 9 heavy vehicles. At the Percostation site the road is located on side sloping ground with frost susceptible silty subgrade. The left side of the road was in a road cut. This section has suffered repeatedly, according to Finnra Spring Thaw Damage Data Base, from severe spring thaw damage since 1996 when the monitoring began.

Figure 33 presents a photo, a GPR cross section profile and thickness interpretation from the Percostation site as well as the location of the probes. Table 6 presents a summary of structures and materials at the site. The GPR profile shows that the structures are thickest in the centre and left part of the road, which is the side primarily being used by heavy vehicles with full loads. The structures become thinner on both sides being only 0.15 m close to road shoulders.

Table 6. Layers of the pavement structure at the Kuorevesi Percostation.

Layer	Depth (mm)	Type of material
Wearing course	0 – 100	Crushed gravel/moraine 0-16 mm
Road Structures	… – 500	Gravel / Crushed rock aggregate 0 – 35…55 mm
Embankment	... – 700	Mixed moraine and gravel
Subgrade		Moist silt with sandy interlayers

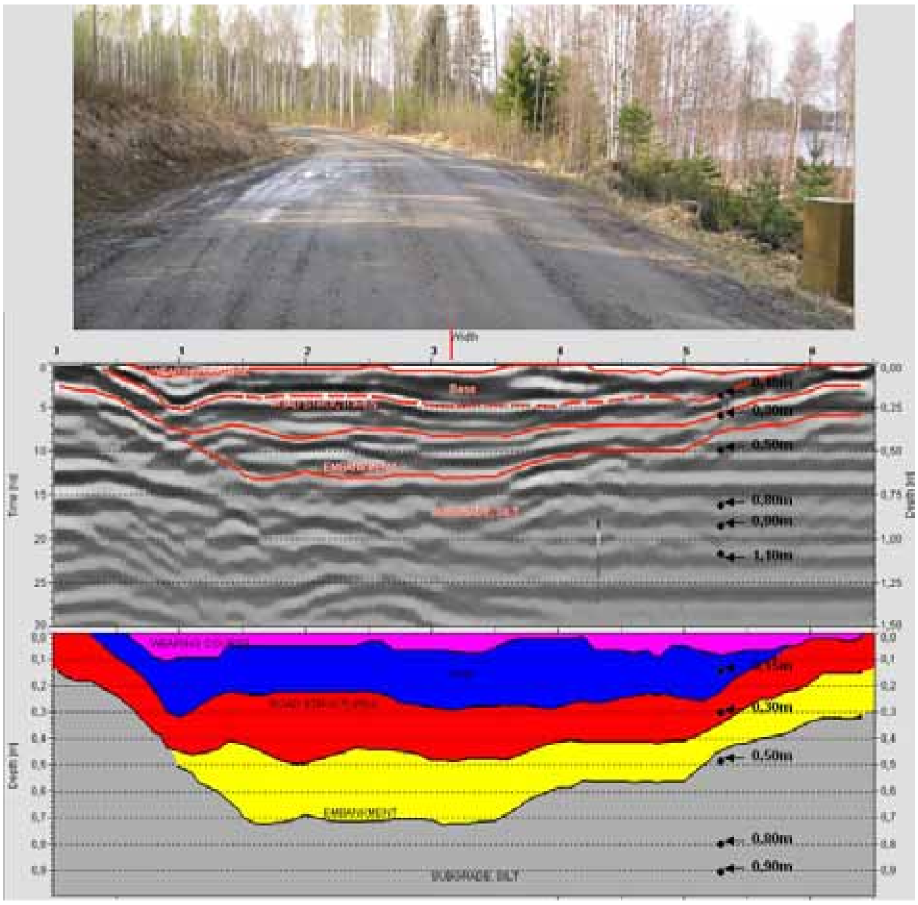

Figure 33. Kuorevesi test site, GPR cross section profile and its interpretation showing the road structure and location of the Percostation probes. The road width at the test site is 6.6 m Trucks with full loads are mainly using the left side of the road.

6.5 Ängesby, Sweden

The Ängesby test section is located on road 607, which is a local road connecting Boden and E4 North of Luleå. This road has formerly been a paved road but due to major problems with pavement condition it was changed back to a gravel road in 2002, the same year that the Percostation was installed (figure 34). In the same year the base course was treated with Mesa, an industrial byproduct from pulp mills used to strengthen gravel roads. The road occasionally has a high number of heavy vehicles when timber trucks are using it to transport timber to the coast; AADT is 440 with 20 heavy trucks.

Figure 34 presents a GPR cross section profile from the Percostation site which shows that in Ängesby the structure also has big changes in a transverse section of the road. On the road shoulders the total thickness of the structure was only about 0.15 m while in the middle of the road it was 0. 55 m. The cross section profile also shows that the old road structures have settled much deeper in the subgrade on the right lane compared to the left lane. This can be explained through the fact that heavy timber trucks with full loads are using the right lane. Figure 34 also presents the location of the probes in the structure.

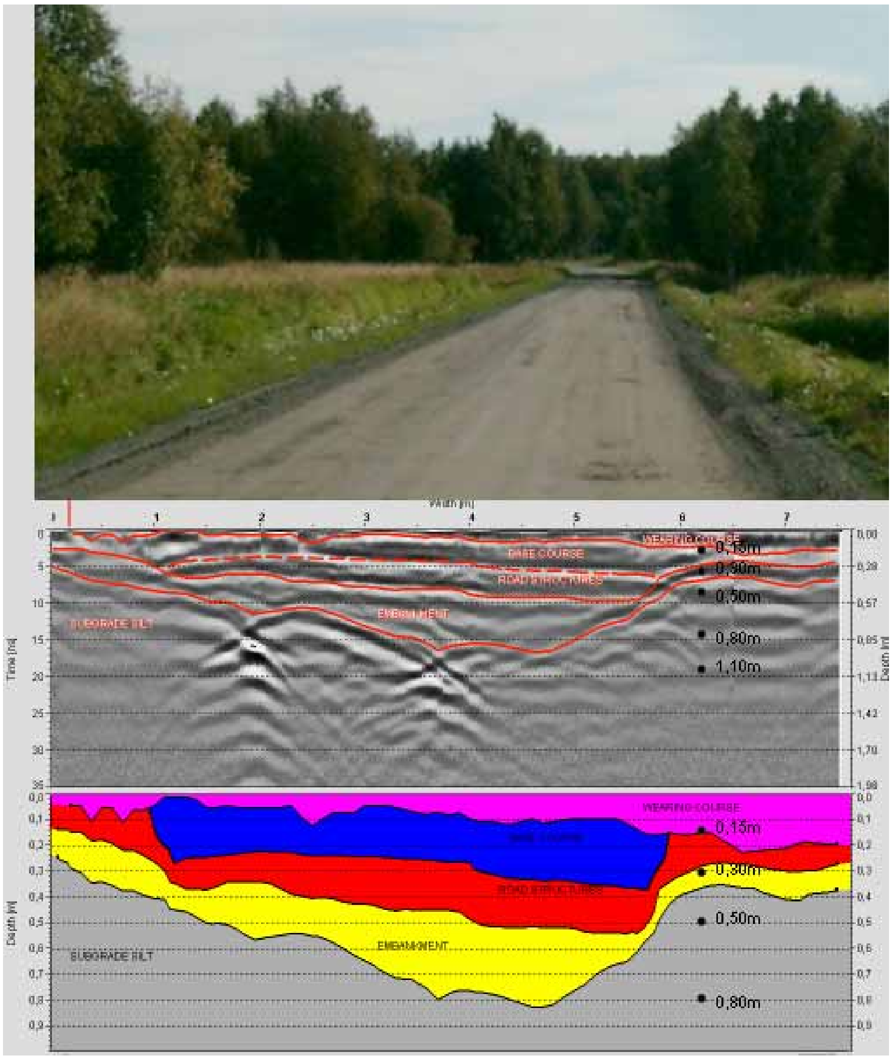

Figure 34. Ängesby test site, GPR cross section profile and its interpretation showing the road structure and the location of Percostation probes. The road width in the test site is 7.5 m. Trucks with full loads are mainly using the "right" lane.

6.6 Garvault, Scotland

The Garvault Percostation test site is located on the B871 Kimbrace – Syre road in the County of Sutherland. B871 is a forest access road and subject to timber extraction traffic - up to 10.000 tonnes each summer season. The road is jointly managed by a Highland Council and Forest Enterprise partnership and has been improved for the last 3 years to accommodate the increased timber traffic use. The traffic volume is very low, AADT in summer is 86 and 25 in winter with 25 % of it heavy traffic. The road is a weak 2.7 – 3,0 m wide single track road with weak shoulders.

The road structure contains 80 – 120 mm of pavement, which is made of several layers of surface dressing (figure 35). Below the pavement the 100 – 120 mm thick base course is made of sandy gravel. The third layer representing the sub base is made of local material, mainly moraine. Under the road structure there is an approximately 10 – 15 cm thick layer of compressed peat.

Many surveys have been conducted on this road in order to evaluate its condition and prepare models and identify weak sections with a high likelihood of being damage under heavy traffic. Figure 36 presents a Road Doctor profile of the Garvault test site, indicating a very weak pavement and base to be main cause for the damage. Figure 37 presents the results of the annual pavement distress analysis for the entire road section since timber haulage began in 2002.

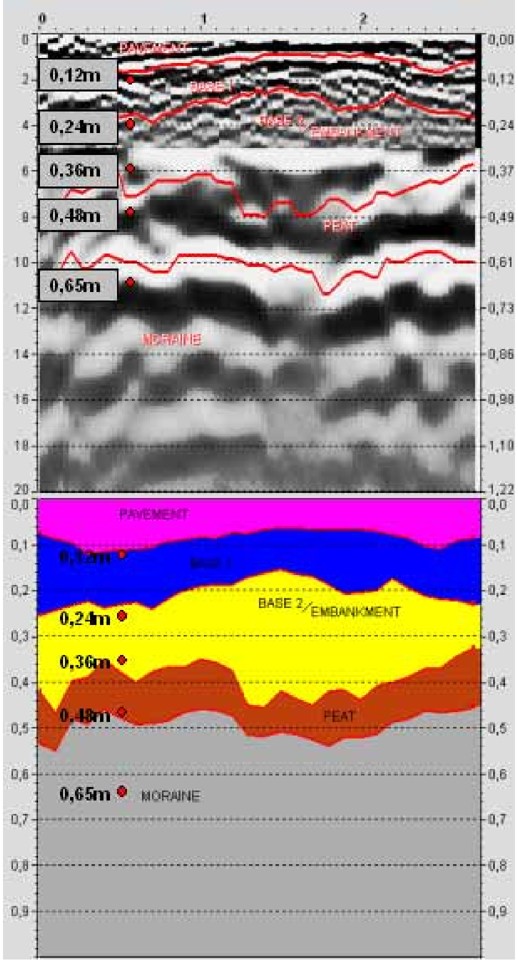

Figure 35. Garvault test site, GPR cross section profile and its interpretation showing the road structure and the location of Percostation probes. The road width at the test site is 3.0 m. Due to the narrowness of the road, trucks with full loads are driving in the road centre.

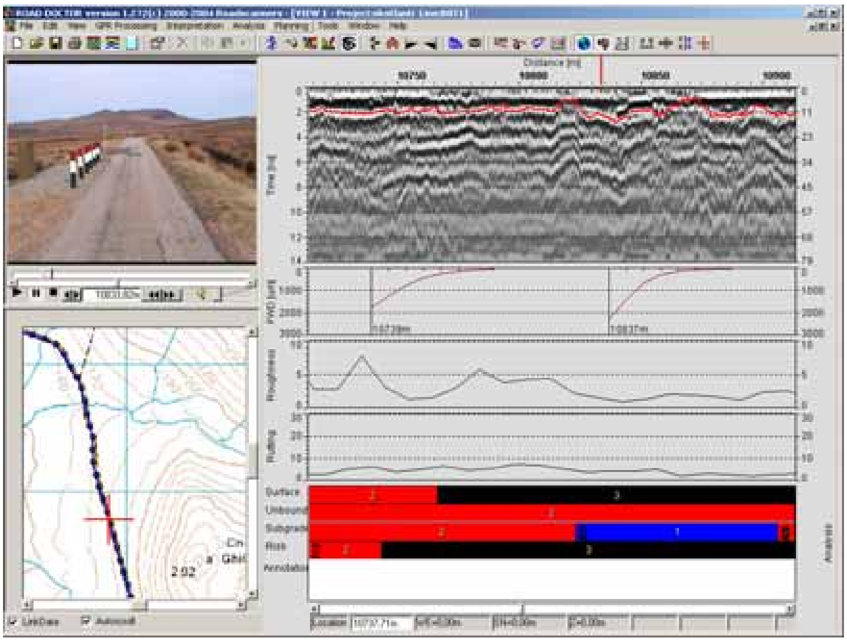

Figure 36. A Road Doctor analysis profile from B871 at the Garvault Percostation site. Figure presents a 1.0 GHz GPR profile, FWD deflection bowls, IRI values, rutting values and a risk analysis that was made to predict pavement damages due to increasing timber haulage. At the Percostation site the risk was classified to be highest mainly due to poor quality pavement and base course. At the site the maximum deflections were about 2000 microns.

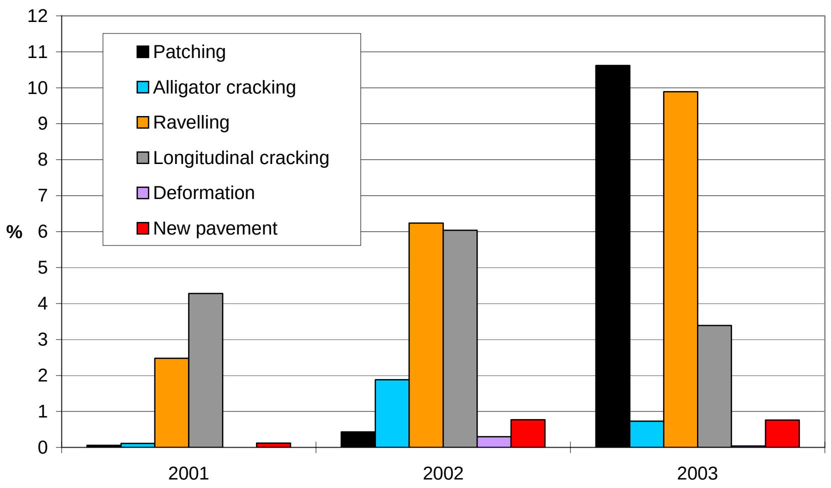

Figure 37. The relative amount of pavement distress on B871 after the timber haulage began in 2002.

7 Research methods

7.1 Percostations

The Percostation measuring technique used at the Roadex test sites is based on dielectric value and electrical conductivity measuring techniques developed by the Estonian company Adek Ltd. The Percometer technique was first used to estimate the frost susceptibility of roads' subgrade soils (Saarenketo 1995a) and later to measure the water susceptibility of base aggregates (Saarenketo 1995b, Saarenketo and Scullion 1996). Currently, the Percometer is most commonly used for taking measurements in the Tube Suction Test (TST), used to measure the water susceptibility of aggregates and bound materials (Saarenketo 1995b, Scullion and Saarenketo 1997, Saarenketo 2000, Saarenketo et al. 2001). However it has also been successfully used in the classification of forests soils for forest regeneration research as well as for assessing moisture damage in buildings and the moisture content of snow.

Figure 38. Garvault Percostation at B871 in Sutherland, Highlands.

A Percometer or Percostation sensor can be used to measure the dielectric value, electrical conductivity and temperature of a material. In dielectric measurements, the Percometer measures the real part of the relative dielectric value, which is mainly a function of the amount free water in the material. The measurement is based on the change in capacitance caused by the material at the tip of the probe. The capacitance measuring frequency is in the range of 40 – 50 MHz. When measuring electrical conductivity, the Percometer uses a measuring frequency of 2 kHz. Electrical conductivity is mainly a function of mineral quality, salt content, water content, colloid content but also temperature. Dielectric measurements, using a tube probe, are reliable when the conductivity of the material being measured is < 1000 µS/cm.

The Percostation differs from the Percometer, in that it offers the option of measuring the dielectric value, electrical conductivity and temperature through a maximum of eight channels. The measurements are normally repeated at 2 hour intervals and the results are saved in the station's memory where they can be read via wireless modem. Normally the Percostation uses solar panels to supply power (figure 38).

7.2 GPR, FWD and DCP tests

7.2.1 Ground Penetrating Radar

Road structures at each test site were measured using the Ground Penetrating Radar (GPR) technique. In GPR surveys the radar antenna transmits a short electromagnetic pulse into the medium and when the pulse reaches an electric interface in the medium, some of the energy will be reflected back while the rest proceeds forward. The GPR system measures the time between transmission and reflection and when this measurement is repeated at short intervals from a moving antenna the results will present a continuous profile of the electric interfaces in the medium.

Figure 39. Measuring GPR cross sections at the Ängesby test site in Sweden using a 400 MHz ground coupled antenna.

All Roadex tests sections were measured with GPR in order to obtain a detailed 3D model of the structures. Both longitudinal and cross sections were measured using both 400 MHz (figure 39) and/or 1.5 GHz ground coupled antennas manufactured by GSSI. The cross sections were measured at 5 m intervals for 20 m on both side of the Percostation. Longitudinal sections were measured on the road centre and on the side where the probes were installed. The GPR results were interpreted using Road Doctor for Windows software and the results were transferred to CAD software to prepare 3D models of the roads.

All other data collected from the site was linked to the Road Doctor projects and they were analysed together with GPR data using Road Doctor software.

7.2.2 Falling Weight Deflectometer

Falling Weight Deflectometer (FWD) surveys were done on the Ängesby, Kuorevesi, Kemijärvi and Koskenkylä test sections during the thawing period in spring 2003. The FWD is a measurement system designed to simulate dynamic axle loads and measure deflections in the road surface caused by this simulated load. During a test a specified load is dropped on the loading plate, which is in contact with the ground and the load level and deflections at different distances from the loading plate are measured. As a result of the measurement a deflection curve is calculated presenting the ability of the pavement structure to carry dynamic loads. The deflection bowl data is then used for backcalculating the moduli values of layers in the pavement structure and subgrade soil.

Figure 40. Finnish Road Enterprise Falling Weight Deflectometer unit used in Roadex II surveys.

The surveys were done with a KUAB falling weight deflectometer unit (figure 40). In Kuorevesi, Kemijärvi and Ängesby measurements were made in three lines, road centre and the two outer wheel paths (figure 41). The Koskenkylä measurements were made in the centre of the both lanes at the same points that were measured in the Koskenkylä Percostation tests from 1999 – 2001 (Saarenketo et al. 2002a).

The FWD measurements at the Kemijärvi and Koskenkylä Percostations were done five times in spring 2003 (23.4., 9.5., 23.5., 6.6. and 21.7.) and twice in spring 2004 (25.5. and 19.6.). In order to monitor the road structures' response to different axle loads each survey point was measures using 12.5 kN, 27.5 kN, 40 kN and 50 kN loads. In addition, measurements using 12.5 kN and 50 kN loads were repeated at 0.3 – 0.5 m intervals. This was done in order to monitor if deflections were different when loading was repeated at the same point.

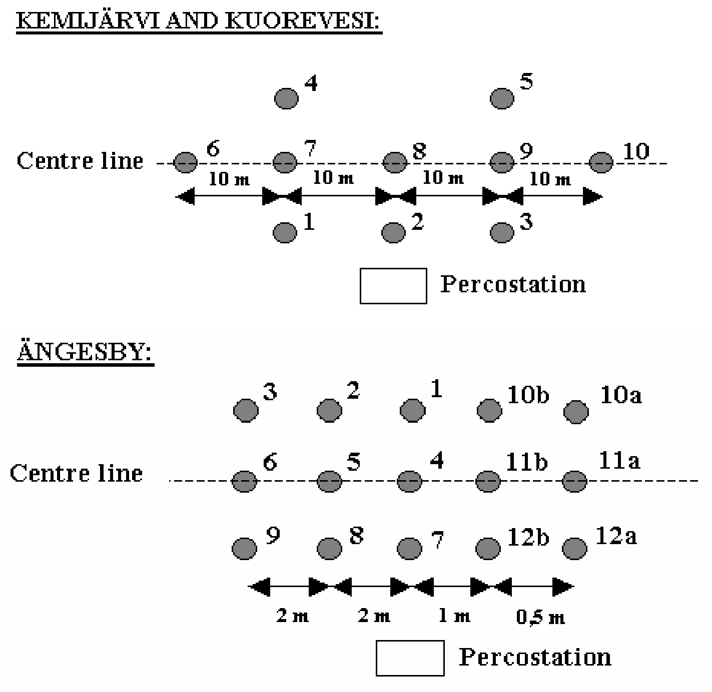

Figure 41. FWD measurement points at the Kemijärvi and Kuorevesi Percostation sites (above) and at Ängesby site (below)

The FWD data collection at the Kuorevesi Percostation was done three times in spring 2003 (22.4., 8.5. and 15.8.) and the load levels in these surveys were 15 kN, 27.5 kN, 40 kN and 50 kN.

Measurements at the Ängesby Percostation were done three times in spring 2003 (15.5., 27.5. and 23.7.). The load levels were slightly higher than those used in Finland (26 kN, 38 kN, 50 kN and 68 kN). In addition measurements using a 2600 N load were done on points 10a, 11a and 12a and a 50 kN load level from points 10b, 11b and 12b (see figure 41).

7.2.3 Dynamic Cone Penetrometer (DCP)

Encouraged by the Norwegian positive experiences of the use of DCP (Roadex 2001) for evaluating changes in the stiffness and thickness of road structures, DCP tests were done in spring 2004 at the Kemijärvi and Kuorevesi test sites. The DCP is a cheap and easy to use instrument where, during the collection of data, a weight is lifted from and dropped onto an anvil on the end of a steel rod with a cone loosely connected to the bottom of the rod (figure 42). The penetration of the cone after one or several drops is measured and the DPI (Dynamic Penetration Index, mm/blow) is recorded. Drops are repeated until the target depth is achieved.

Figure 42. DCP tests at Kemijärvi test site in spring 2004 using the Norwegian DCP system.

The DCP results can be used to measure the depth of structural interfaces in a road structure and subgrade soil but it is also good for measuring thawing frost line. Figure 43 presents a DPI profile measured at the Kuorevesi Percostation on 5.5.2004.

The DCP results have been related to strength and deformation properties of materials in a number of studies. The DPI has mainly been related to CBR (California Bearing Ratio) values. In this survey the DCP results were used to calculate modulus values using a formula used by the Norwegian Road Administration (Roadex CD-rom 1998-2001).

In Roadex II project the DCP surveys were done at the Kemijärvi and Kuorevesi Percostations several times in spring 2004. In Kemijärvi the measurements were done 8 times (29.4., 16.5., 21.5., 25.5., 31.5., 8.6., 15.7. and 1.7.) and in Kuorevesi twice (5.5. and 2.7.). The surveys were done in five places, both the road shoulders, outer wheelpaths and the road centre.

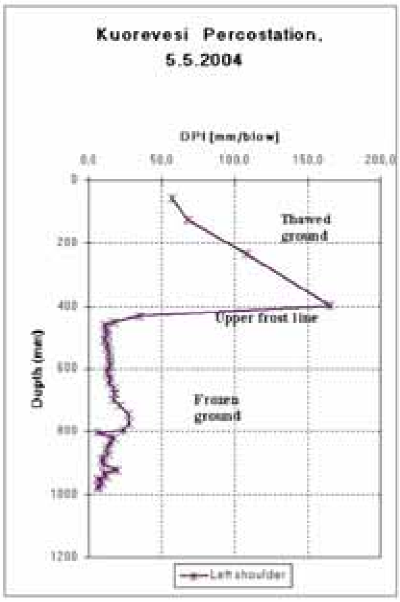

Figure 43. DPI profile from Kuorevesi test site measured 5.5.2004.

7.3 Frost heave monitoring

Frost heave and thaw settlement was monitored on the gravel road tests section in Ängesby Sweden and Kemijärvi Finland by means of levelling. The measurement covered a selected area around the Percostation so that road surface readings were taken from both the road centre and road shoulders. Frost heave was measured at the Kuorevesi test section in winter 2002 – 2003 from a single point above the Percostation sensors. Frost heave was also evaluated from the portable profilometer surveys done by Tampere University of Technology.

7.4 Other surveys

In order to monitor the surface condition of the roads during the spring thaw weakening at the Ängesby, Kuorevesi and Kemijärvi Percostation sites a series of photos were taken daily in spring 2003.

8 ROADEX field test results

8.1 Percostation monitoring results

8.1.1. General

Roadex II project has collected Percostation data regarding the changes in dielectric values, electrical conductivity and temperature in road structures and subgrade soils and air temperature for two winters 2002 – 2004. The following sections will highlight some of the key results and findings from data.

8.1.2. Garvault

In Garvault, Scotland, collection of the Percostation data started in spring 2003 when the freeze – thaw cycles for that winter were already over. However once the extensive timber haulage started it could be observed that especially the dielectric value of base course just below the pavement started to rise (figure 44). At the same time as these high dielectric values were measured, field observations showed that the pavement in B871 had started to show severe distress in many locations (see figure 45). After that timber haulage was temporarily stopped and loads were monitored more carefully and more attention was paid to control distances between trucks. Once these measures were taken dielectric values started to decrease and the rate at which new distress locations appeared also markedly decreased.

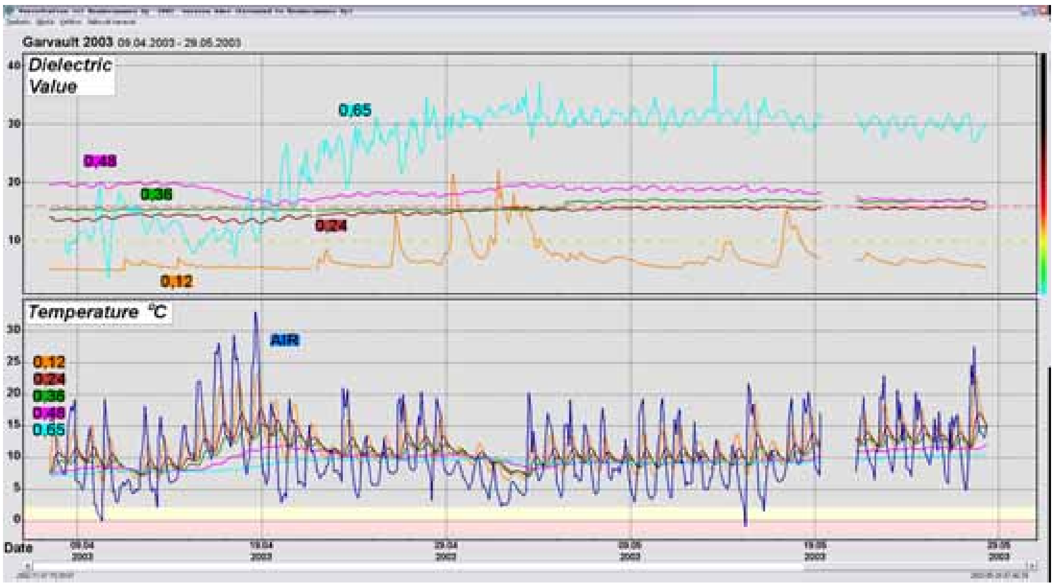

Figure 44. Percostation results from Garvault Percostation at B871during the timber haulage period in spring and summer 2003. The timber haulage started in early April and was closed in early May when the road started to fail quickly.

The Percostation monitoring continued through winter 2003-2004 and figure 46 presents a great example of the combined effect of cryo suction and rainfall on the dielectric value of the base course below the pavement. In the figure this dielectric value is presented together with temperature values measured using the same probe, air temperature and daily rainfall values measured at the nearest weather station.

This figure shows that after the third and a longer freeze-thaw cycle followed by a few days of rainfall, about 5-12 mm daily, the dielectric values started to rise rapidly above the critical level of 16. After that the base dried quickly and the dielectric value (moisture content) always increased about one day after the air temperature dropped below 0°C. If these freeze-thaw cycles were followed by rainy days these values were even higher. When the base course material started to dry a heavy rain had a minor effect on the dielectric value, as the results from January 6th 2004 show.

Figure 45. Pavement failures at B871 in early May 2003.

According to the Percostation results the critical time on road B871 in winter 2003-2004 was from mid December to mid February. After that there were still some frost nights but the temperature in those layers were so high above zero that cryo suction could not have affected the moisture content. However resent results from winter 2004-2005 have shown that the critical period can last up to mid March.

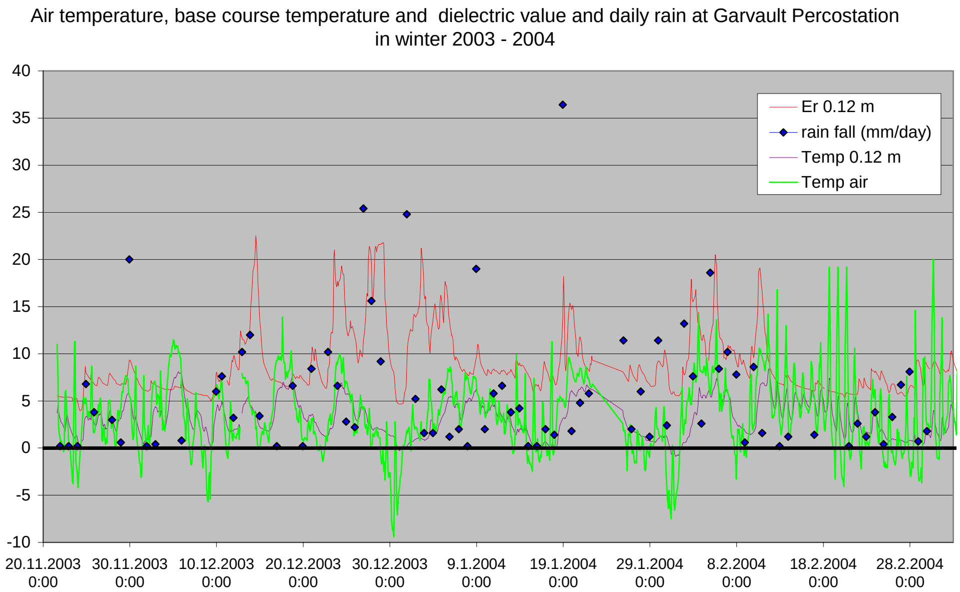

Figure 46. Dielectric value and temperature of the base course at a depth of 0.12 m presented together with the air temperature and daily rainfall at the Garvault Percostation in winter 2003 – 2004. Dielectric values higher than 16 are critical for base course.

8.1.2 Ängesby, Sweden

Table 7 presents a summary of Percostation frost monitoring results from winters 2002-2003 and 2003-2004. In monitoring the frost depths, Percostation data from Ängesby showed that winter 2002-2003 was much colder than winter 2003-2004. For instance while the subgrade soil at a depth of 0.8 and 1.1 m was frozen for a long time prior to March 2003, in 2004 these probes did not detect any freezing at all. The maximum dielectric values indicate that the moisture content was roughly at the same level during both springs.

Table 7. Summary of Ängesby Percostation results from winters 2002-2003 and 2003-2004.

Depth (m)	Freeze 2002-2003	Freeze 2003-2004	Thaw 2003	Max Er 2003	Thaw 2004	Max Er 2004
0.15	31.10.2002	10.11.2003	14.4.2003	18	13.4.2004	16
0.30	02.11.2002	12.11.2003	17.4.2003	18	15.4.2004	18
0.50	27.11.2002	20.12.2003	19.5.2003	68	11.5.2004	60
0.80	before 18.03.2003	no freezing	11.6.2003	> 35	no freezing	-
1.10	before 18.03.2003	no freezing	02.7.2003	38	no freezing	36

Figure 47 presents Percostation data from the thawing period in spring 2003 and Figure 48 presents photos taken from the site during the thawing period. The data shows that the road surface thawed, thanks to warm period, temporarily in late March. This thawing or partial thawing could be seen as an increase in electrical conductivity values. In late March cold nights could keep the roads surface frozen. The spring thaw weakening period finally started in mid April when probes at a depth of 0.15 m showed values indicative of thawed structures and three days later thawing had penetrated to a depth of 0.3 m. Dielectric values from both probes showed values less than 20 and they quickly dropped under the critical value of 16.

The next probe to indicate that thawing had occurred was installed at a depth of 0.5 m in silty subgrade, about 0.1 m below the road structures. The readings from this probe showed that there was a lot of segregation ice at that depth because it took almost one month (May 19th) for the frost to thaw from 0.3 m to 0.5 m. After thawing the dielectric values were at a level of 60 which, since the Er value of pure water is 80, would indicate that the road was, at that time, practically floating on water above the thawing ice lenses. The subgrade thawed to a deeper level of 0.8 m on June 11th and quite surprisingly at a depth of 1.1 m the ice lenses did not disappear until July 2nd in 2003.

The pumping effect of a heavy vehicle and the concept of recovery time can clearly be seen in the electrical conductivity values from the probe 0.3 m. The first high peak can be seen as being related to the thawing and after that values started to settle until the subgrade started to that thaw at a depth of 0.5 m. These peaks show very high values and long recovery times and they became especially high in early June once the weight restrictions had been removed. Along with these peaks in conductivity small peaks in dielectric value can also be seen which is indicative of water being squeezed upwards from the subgrade. These unusual incidences can be explained in that heavy trucks, while passing the site, caused the water from the plastic silt containing high amounts of clay colloids to be pumped upwards. Another theory is that these peaks are related to compounds released from the Mesa layer by rainwater but there is no evidence to support that.

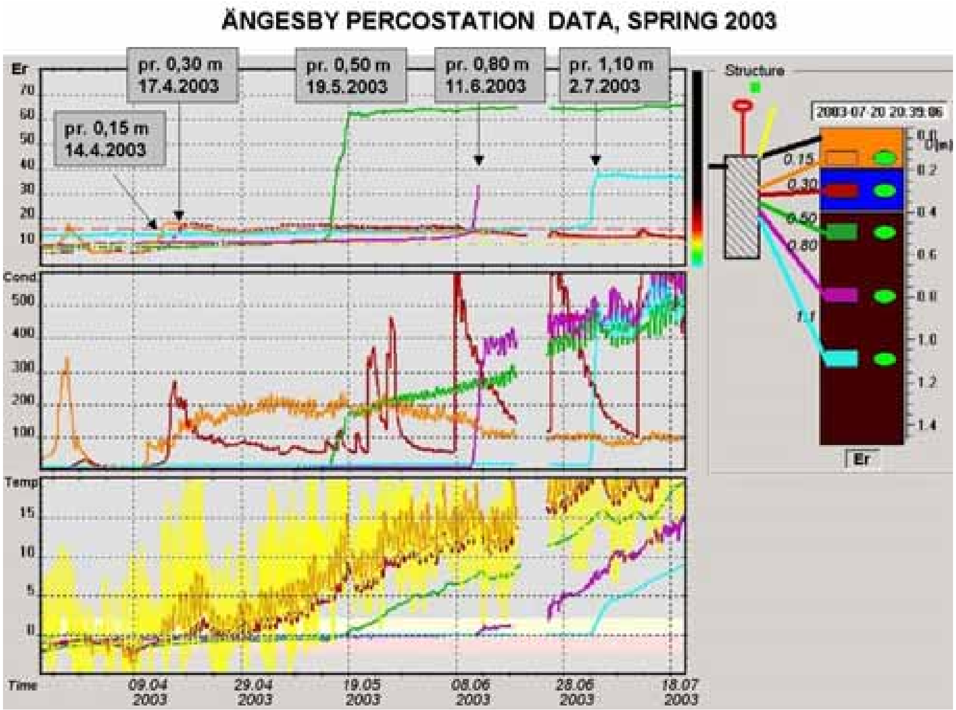

Figure 47. Percostation results from Ängesby test site from spring 2003.

Figure 48. Percostation results from Ängesby test site from spring 2003.

8.1.3 Kuorevesi

Table 8 presents a summary of the Kuorevesi Percostation results from winters 2002-2003 and 2003-2004. In spring 2003 the first indications of surface thaw were measured in mid April when electrical conductivity values and dielectric values started to rise at 0.15 m depth (figure 49). This indicated that melting water from the surface was infiltrating the frozen structures. This can also be seen in daily fluctuations in the values which were very clear. The final thawing started around May 1st 2003 when probes at a depth of 0.15 m and 0.3 m started to thaw at almost the same time. A few days later, the probe at a depth of 0.5 m also measured values indicative of thawing. The probe at a depth of 0.7-0.8 m measured thawing on May 11th, the probe at a depth of 0.9 m on May 23rd and the deepest probe only two days later on May 23rd 2003.

Table 8. Summary of Kuorevesi Percostation results from winter seasons 2002-2003 and 2003-2004.

Depth (m)	Freeze 2002-2003	Freeze 2003-2004	Final thaw 2003	Max Er 2003	Final thaw 2004	Max Er 2004
0.15	10.11.2002	15.12.2003	1.5.2003	19	10.4.2004	15
0.30	13.11.2002	20.12.2003	3.5.2003	22	21.4.2004	19
0.50	15.11.2002	22.12.2003	7.5.2003	28 / 40	25.4.2004	23 / 37
0.80	10.12.2002	14.1.2004	13.05.2003	23	5.5.2004	22
0.90	10.1.2003	no freezing	22.05.2003	24	no freezing	23
1.10	13.1.2003	no freezing	25.05.2003	25	no freezing	22

As in Ängesby Sweden the results from Kuorevesi also illustrated that the winter of 2003-2004 was milder than winter 2002-2003 and dielectric values also indicated that the spring thaw weakening was not as severe during the latter spring.

In spring 2003 photos were also taken daily at the Kuorevesi Percostation site and photos of the different seasons verified the results obtained from the Kuorevesi Percostation (figure 50). Photos show that the critical period started in early May and lasted until May 20, 2003.

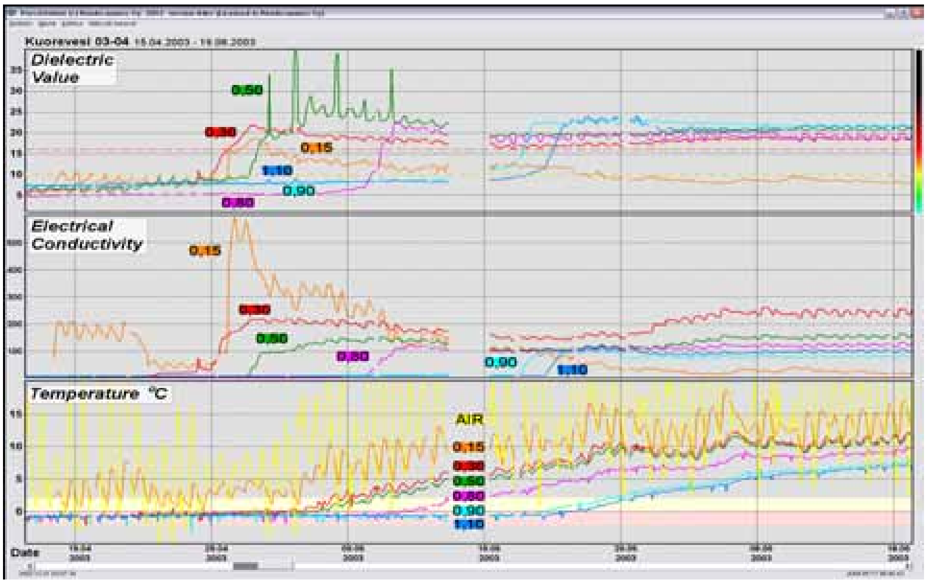

Figure 49. Data from the Kuorevesi Percostation from spring 2003.

Figure 50. Photos from the Kuorevesi Percostation site during the spring thaw period in 2003.

8.1.4 Kemijärvi

Table 9 presents a summary of the Kemijärvi Percostation results from winter 2002-2003 and figure 51 presents Percostation readings from spring 2003. As a result of unexpected high frost heave values at the Kemijärvi test site (360 mm, see chapter 8.2.2) the probe cables were damaged and, as such, continuous readings could not be obtained from all of the probes. The damaged probe, installed at depth of 0.30 m, was replaced with a reserve probe on April 24th – and soon after it was damaged again by frost settlement and another probe was installed, at a depth of 0.40 m, on May 21st.

Table 9. Freezing date in winter 2002-2003, thawing date and maximum dielectric values during the spring thaw period in spring 2003 at the Kemijärvi Percostation, Finland.

Depth (m)	Freeze 2002-2003	Thaw 2003	Max Er 2003
0.15	19.10.2002	14.4.2003	22
0.30	25.10.2002		45
0.50	3.11.2002	7.5.2003	
0.80	5.1.2003	12.6.2003	28
1.10	3.2.2003	25.6.2003	30

An interesting feature was that dielectric value from the probe installed at a depth of 0.40 m started to rise quickly after May 25th and, at the same time, several gravel roads in the Kemijärvi area that did not have load restrictions and were being used by heavy traffic experienced severe and sudden failures. An example of these failure from nearby the Kemijärvi test site is presented in figure 14. Figure 15, taken slightly after the worst period, from Kemijärvi Percostation site presents the plastic flowing of silt trough the road shoulders. Figure 52 presents photos taken from the test site during the spring thaw period 2003.

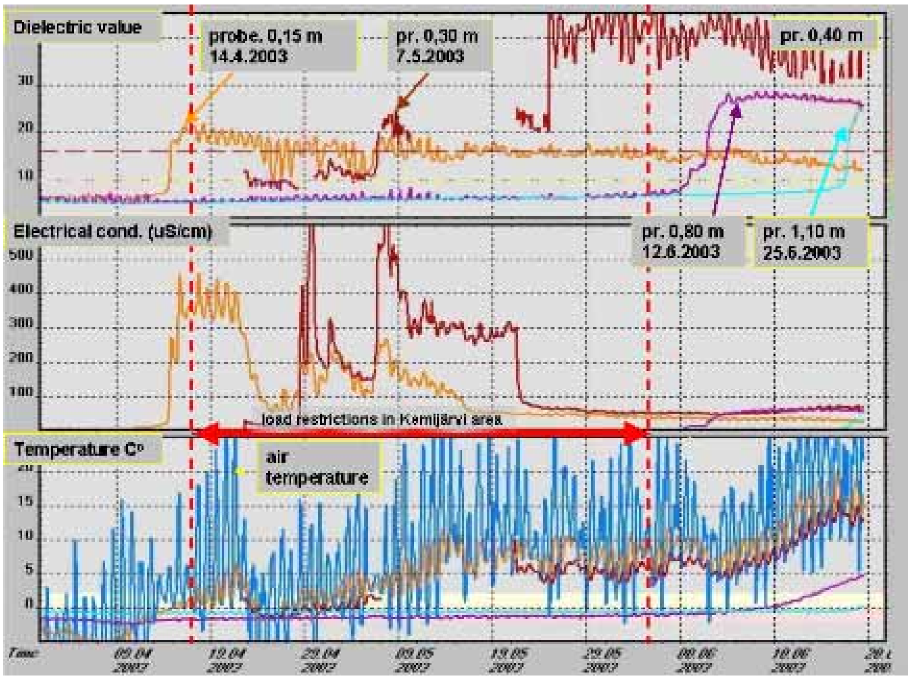

Figure 51. Kemijärvi Percostation results from spring 2003. Probe 0.30 was replaced with a new probe on 23.04.2003 and after its malfunction it was replaced by a new probe at a depth of 0.40 m on 23.05.2003. Figure also shows the period of load restrictions in the Kemijärvi area which was from April 17th to of June 5th 2003.

Figure 52. Photos taken from the Kemijärvi Percostation site during the spring thaw period in 2003.

8.1.5 Koskenkylä

Spring thaw weakening has been monitored in Koskenkylä, near Rovaniemi, Finland since spring 2000. Table 10 present a summary of the thawing dates at different depths from 2000 – 2004 and maximum dielectric values. The probe at 0.15 m measured thawing values earliest in spring 2004 (April 8th) and at the latest in 2001 when thawing started on April 20th after several freeze thaw cycles in mid April (figure 53). The thawing period has lasted normally about 2 weeks but in 2004 thawing from 0.15 m to 0.80 m took almost one month. The highest dielectric values were measured in the critical sub base course at a depth of 0.50 m in spring 2001 when the maximum measured value was 30. Figure 54 presents the Percostation monitoring data from spring 2003. In this year the critical period when the subgrade had its highest values lasted eight days starting from May 6th.

Table 10. Summary of Koskenkylä Percostation results from 2000-2004. Table presents the dates for final thawing and maximum dielectric value measured in each year.

Depth (m)	Thaw 2000	Thaw 2001	Thaw 2002	Thaw 2003	Thaw 2004	Er 2000	Er 2001	Er 2002	Er 2003	Er 2004
0.15	11.04.	20.04.	13.04.	15.04.	08.04	14	14	12	14	12
0.30	12.04.	22.04.	13.04.	17.04.	-	17	13	12	12	-
0.50	25.04.	04.05	24.04.	05.05.	30.04.	30	23	-	27	-
0.80	-	16.05	-	15.05.	08.05.	-	15	-	19	20
1.10	26.04.	05.05	-	24.05.	-	10	7	-	13	-

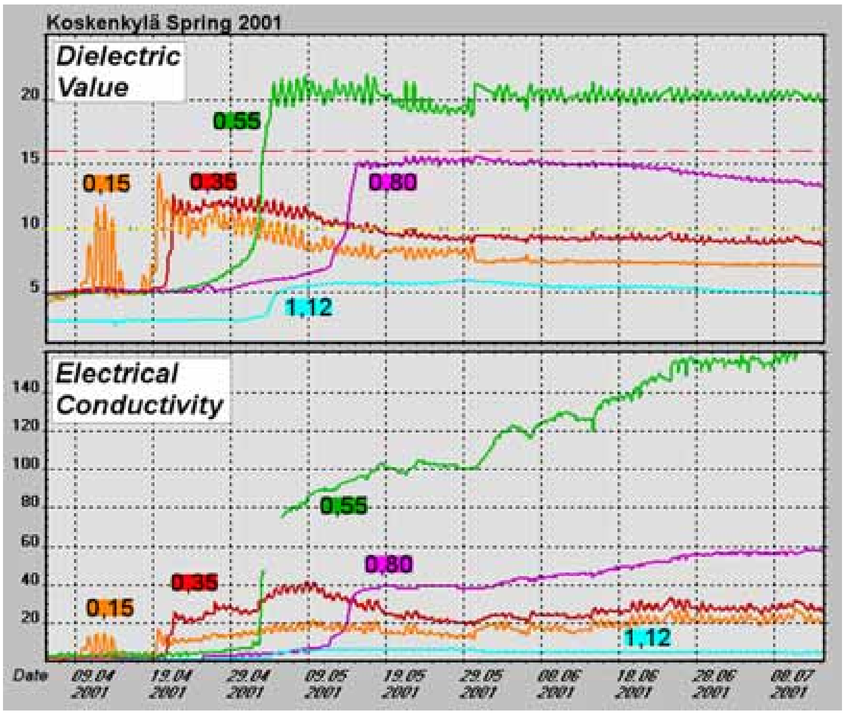

Figure 53. Percostation results from the Koskenkylä test site from spring 2001.

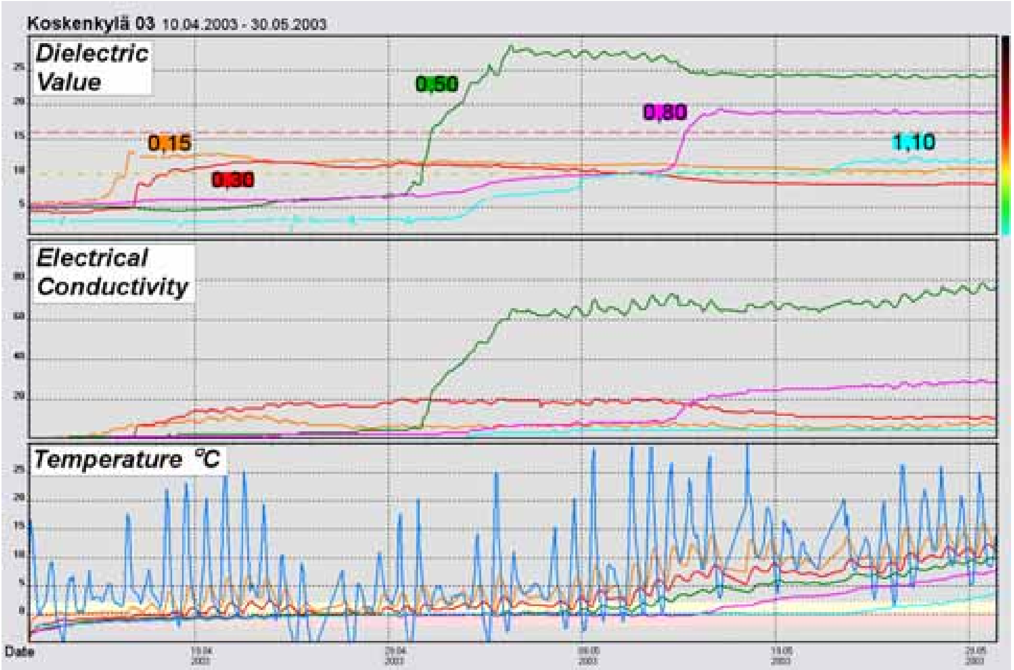

Figure 54. Percostation results from the Koskenkylä test site from spring 2003.

An interesting comparison can be made when the two different spring thaw periods from 2001 and 2004 (figures 53 and 54) are compared. In 2001 the probes were located at a site where the pavement had cracking and the effect of this can be seen in high daily variations which are indicative of evaporation through the pavement. In 2004 the probes were relocated to an area where the pavement did not have cracking and, as a result, evaporation can hardly be seen. Figure 55 present the changes in dielectric values in early May 2001 at depths of 0.15 and 0.30 m. The data shows thermodynamic water flow in the base course. When the sun sets and the temperature becomes cooler, the dielectric value from the top, 0.15 m, probe starts to rise demonstrating that this layer is adsorbing water from deeper down. The dielectric values from the probe at 0.30 m are decreasing indicating that this layer is losing water to the upper base layer. In the morning, after the sun rises, the dielectric value of the surface starts to decrease again indicating evaporation through the pavement and at the same time the increasing values of probe at 0.30m indicates that this layer is adsorbing water from deeper layers.

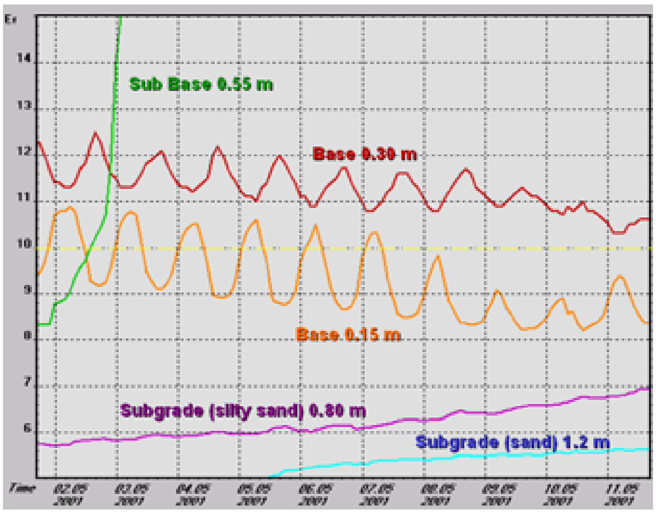

Figure 55. Koskenkylä Percostation dielectric values 01.05.-12.05.2001

8.2 Frost heave and thaw settlement

8.2.1 Ängesby

The most detailed frost heave monitoring in the Roadex II project was done at the Ängesby site in Sweden where frost heave was monitored throughout the entire winter of 2002 – 2003. A summary of the results from the frost heave measurements from cross section 0 m, where the Percostation probes were installed is presented in figure 56. The frost depth at the time of each frost heave measurement has been evaluated from the Percostation data. Figure 57 presents contour maps made from the road surface during the freezing period in fall 2002 – winter 2003 and the contour map in figure 58 presents the road surface level during the thawing period in spring 2003.

During the early phase of the freezing period the frost heave, caused by the freezing of the road structures was only 20 – 40 mm, but when the frost penetrated to the subgrade silt, the frost heave was about 50 mm when the frost had penetrated from 0.35 m to 0.50 m and the frost heave increase by another 50 mm when the frost had penetrated from 0.50 m to 0.70 m. After the frost line had penetrated deeper than 0.7 m the measured frost heave was very small. An interesting feature of the Ängesby test site was that the measured frost heave was smallest in the road centre. The maximum frost heave values correlated with the total thickness of the road structures. Contour maps in figure 57 show that the frost heave started first on the roadsides and that the frost heave was highest on the right side of the road.

The thawing values confirmed that the frost had caused the road structures to expand by only 20 – 40 mm and major thaw settlement started when the thawing reached the subgrade. The contour maps in figure 58 also show that the thaw settlement was at its highest on road shoulders where structure thickness was also the thinnest. The deeper settlement of the right hand side can also explain why the GPR cross section shows the old road structures inclined to the right.

Compared with the other gravel road test sites the absolute frost heave values were much smaller in Ängesby. This can be explained in that the ground water level was very close to the road surface, roughly 0.3 – 0.4 m from the road surface.

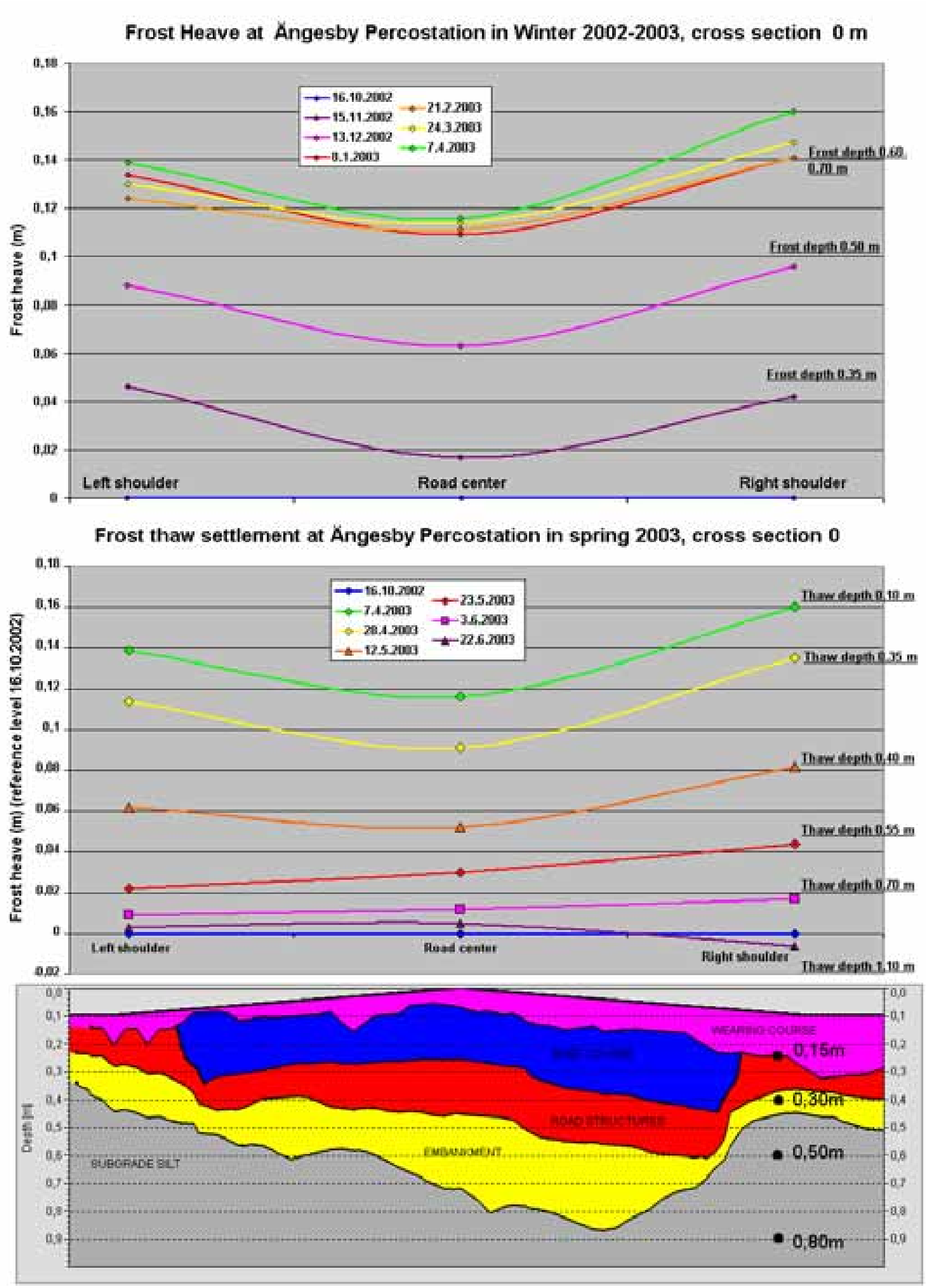

Figure 56. A summary of the frost heave (top) and thaw settlement (middle) measurement results presented together with frost level monitoring results collected from the Percostation in winter 2002 – 2003 and the structural cross section data from Ängesby Percostation. The right side of the road is south facing and more exposed to solar radiation.

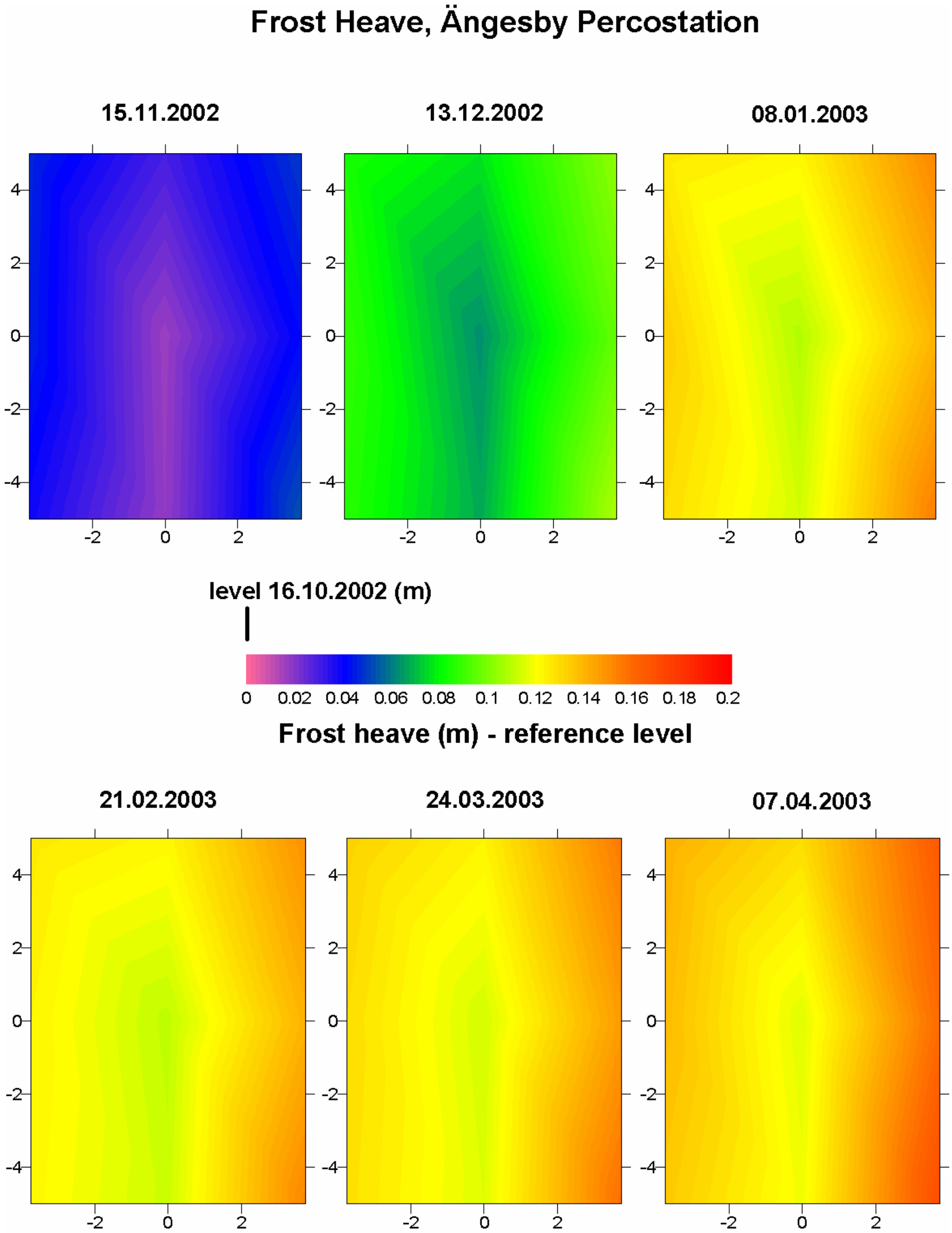

Figure 57. A contour map of the frost heave measurement results from the Ängesby Percostation during the freezing period in winter 2002 – 2003. The reference level is the road surface level measured on October 16th, 2002.

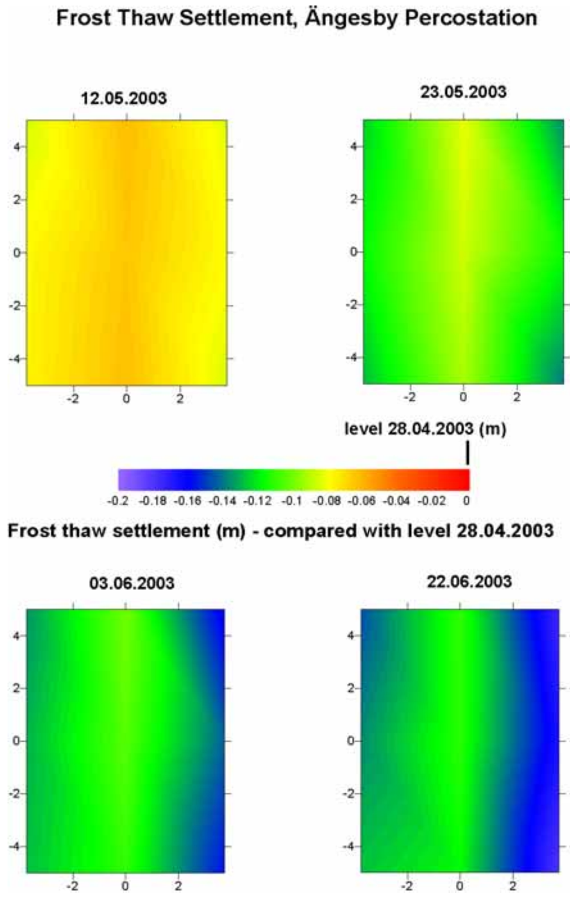

Figure 58. A contour map of the frost thaw settlement measurement results from the Ängesby Percostation during the thawing period in spring 2003. The reference level is the road surface level measured on April 28th, 2003. The right side of the road is south facing and more exposed to solar radiation.

8.2.2. Kemijärvi

Frost heave and thaw settlement was also monitored in Kemijärvi in winter 2002 – 2003. Compared to the rest of the Roadex test sites, the frost heave values were the highest at this site with maximum values that were nearly 0.4 m. Figure 59 presents the results of the frost heave and thaw settlement measurements on the 0 m point, where the probes are located.

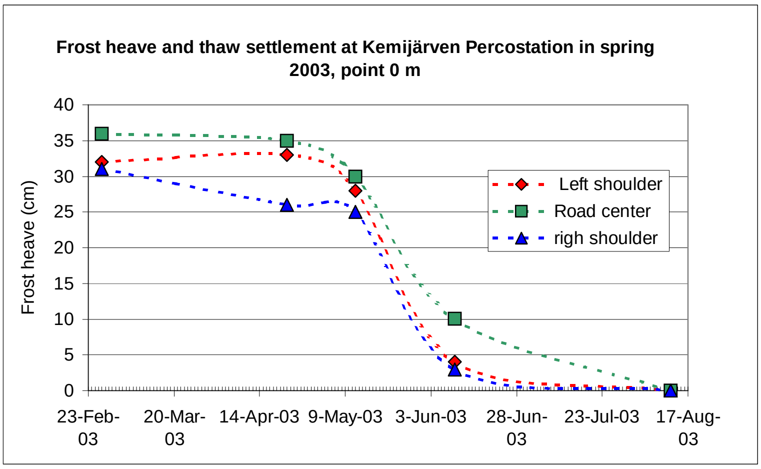

Figure 59. Frost heave leveling results during the spring 2003 at the 0 m point at the Kemijärvi Percostation.

During the first measurements on April 22nd, the upper frost line had thawed 0.15 0.25 m from the road surface. Interestingly, at that time, the left shoulder, which was on the southern and sunny side of the road, had higher frost heave values compared to the values measured in February. On May 12th the frost had thawed approximately to a level of 0.30 – 0.40 m from the road surface indicating that the frost heave in the road structures was only 50 – 60 mm. The biggest settlement happened between May 12th and June 10th, when the frost line had thawed roughly to a level of 0.80 m from the road surface level at that time. After that the road continued to settle about 100 mm in road centre and about 40-50 mm on the shoulders.

Figure 60. A 30 cm high vertical shear zone beside the right road shoulder at the Kemijärvi Percostation during spring 2004.

Even though the frost heave values were very high the road acted as a rigid plate pushing up and out through the road shoulders. This can be seen clearly in figure 60. The "plate" type behaviour can also be seen in figure 61, which presents contour maps of the road surface during the thaw settlement in spring 2003.

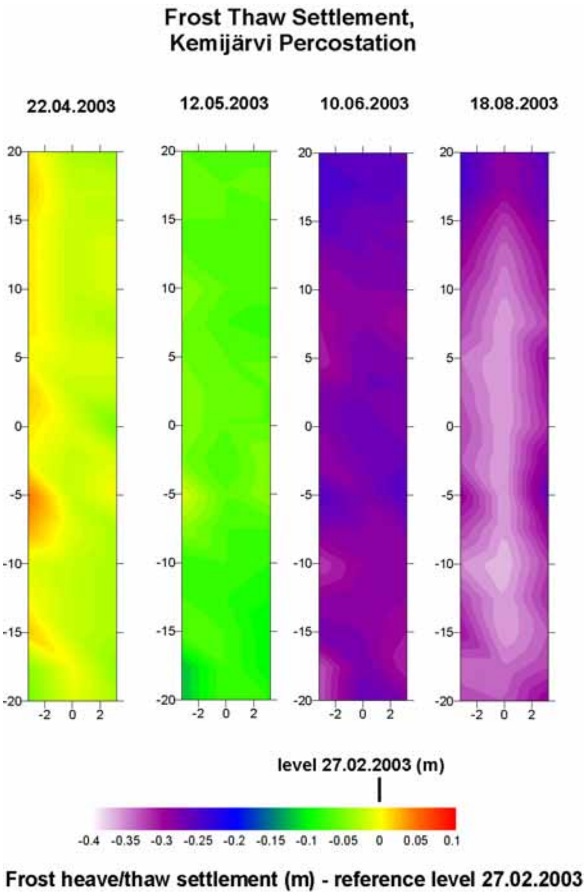

Figure 61. Contour maps of the road surface level from the Kemijärvi test site during the thaw settlement in spring 2003. The reference level is the level that was measured on February 27th, 2003. The left side of the road is south facing and more exposed to solar radiation.

8.2.3 Kuorevesi

The frost heave at Kuorevesi test site was measured a few times during winter 2002 - 2003. The measurements were done above the Percostation probes (point 0 in figure 63 and 64). The results (figure 62) show that frost heave was around 60 mm on November 18th, 2002 when the Percostation indicated that the freezing front had just reached the subgrade at a depth of 0.50 m. The 25 cm frost heave measured on March 18th 2003 presents the maximum frost heave at the Kuorevesi site.

During the thaw settlement in spring 2003, the frost heave value in the road centre was still 18,5 cm on May 5th, when the 0.50 m probe indicated thawing in that level. This and the measurements done in fall 2003 indicate that the frost heave in the road structures was about 60 mm and the frost heave due to segregation ice in the silt subgrade was about 180 mm.

During the winters of 2002 – 2003 and 2003 – 2004 the frost heave and thaw settlement was measured a few times by the Technical University of Tampere using a manual profilometer. The results from these measurements are presented in Figures 63 and 64. During the thawing period in 2003 and 2004 the frost heave was highest in the road centre. On both measurement dates, May 15th in 2003 and May 5th in 2004, the frost line thawing depth was about 0.7 – 0.8 m. The results in figure 64 show that the frost heave began on the left side of the road where there was more moisture present.

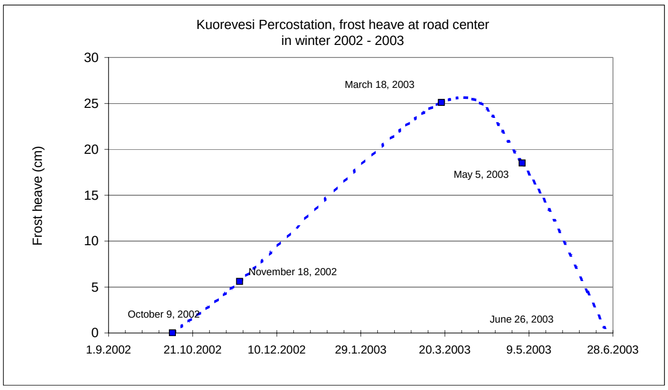

Figure 62. Frost heave measurement results from the Kuorevesi Percostation in winter 2002 – 2003. Measurements were made in the road center.

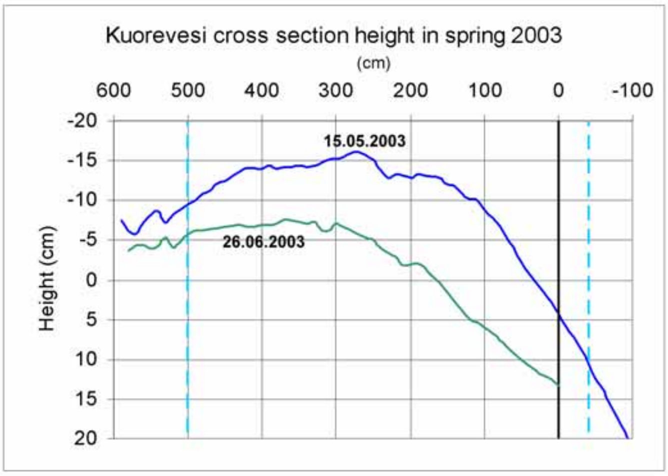

Figure 63. Cross section profiles from the Kuorevesi Percostation measured on 15.05.2003 and 26.06.2003.

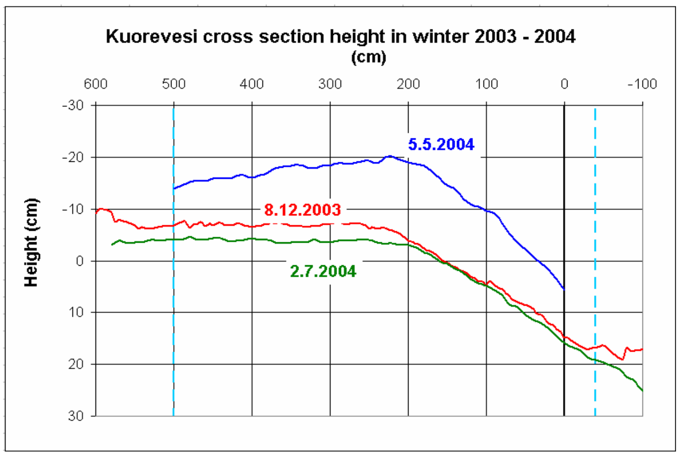

Figure 64. Cross section profiles measured at Kuorevesi Percostation 8.12.2003, 5.5.2004 and 2.7.2004.

8.2.4 Koskenkylä

In the Roadex II project frost heave measurements were not made at the Koskenkylä test site but there was older data available from the site. Figure 65 presents frost heave contour maps of the test area in winter 2000 – 2001 and figure 66 presents contour maps of the frost thaw settlement. The results show that the frost heave was greatest in those areas of road where the old poor quality gravel road material is thickest. The maps also show that there were no major changes in frost heave after January 16th in 2001, when the sub base was frozen, indicating that the greatest part of frost heave occurs in the sub base. The contour maps from the thawing period (figure 66) show that thaw settlement first started on the left side of the road, which is more exposed to the solar radiation. This type of differential settlement is critical to the pavement performance and the worst pavement distress could be observed on this side. The greatest part of thaw settlement took place between April 23rd and May 8th when the sub base thawed. After that hardly any further settlement could be measured.

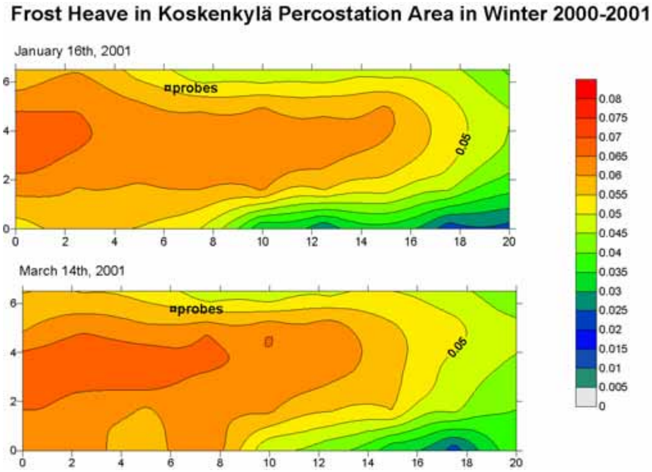

Figure 65. Frost heave at the Koskenkylä test section measured on January 16th and March 14th 2001.

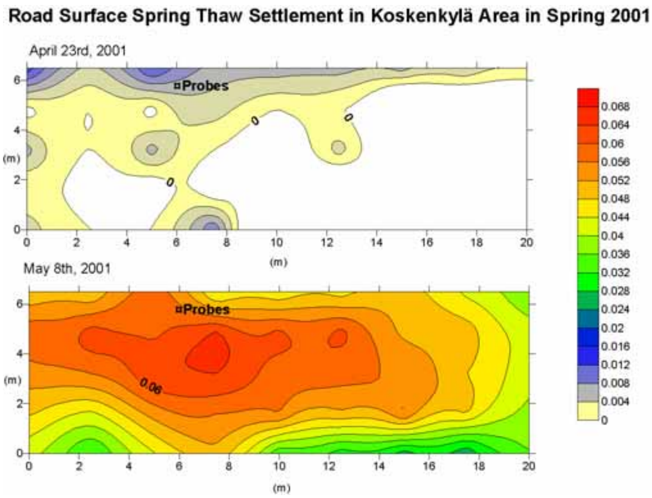

Figure 66. Frost thaw settlement at the Koskenkylä test section in spring 2001 measured on April 23rd and May 8th 2001. The reference level is March 14th 2001.

8.3 Bearing capacity

8.3.1 Kemijärvi FWD results

As already mentioned in chapter 7.2, FWD measurements were made at the Kemijärvi Percostation five times during the year 2003 and twice in 2004. Figure 67 presents the results of FWD surveys repeated at the same point using increasing load levels of 12.5 kN, 27.5 kN, 40 kN and 50 kN respectively. The figure shows that the load level does not have a noticeable effect on the shape of the deflection bowl. When comparing deflection values of different load levels during the spring thaw period with 50 kN deflection bowl in July 21st representing "summer value" it can be seen that deflection values of 27.5 kN load are roughly the same as "safe" summer values.

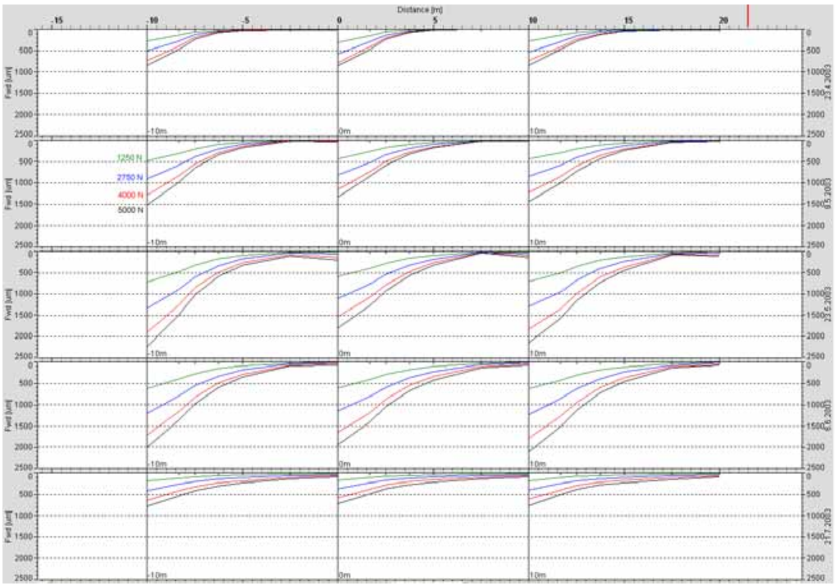

Figure 67. FWD deflection bowls measured at four load levels at the Kemijärvi Percostation in spring and summer 2003. The data was collected from the right wheel path. The measuring dates starting from the top are: 24.3., 9.5., 25.5., 6.5. and 21.7.

The effect of repeated and increasing loads, described above, compared with a single load was tested by using 12.5 kN and 50 kN loads about 0.3 – 0.5 m away from the original survey points.

Figure 68 presents deflection bowls measured under a 50 kN load during spring and summer 2003. During the weakest period on 23.5.2003 the maximum deflection was about 3000 µm in the left wheel path and road centre. The deflections measured in the right wheel path were, during the thawing period, clearly smaller than those from the road centre and left side of the road. This can be explained in that the frost was thawing faster on the left side of the road but also by the fact that trucks with full loads were using the left side. During the spring thaw, plastic subgrade silt was also squeezing through the left shoulder but not so much through the right shoulder (see figure 15).

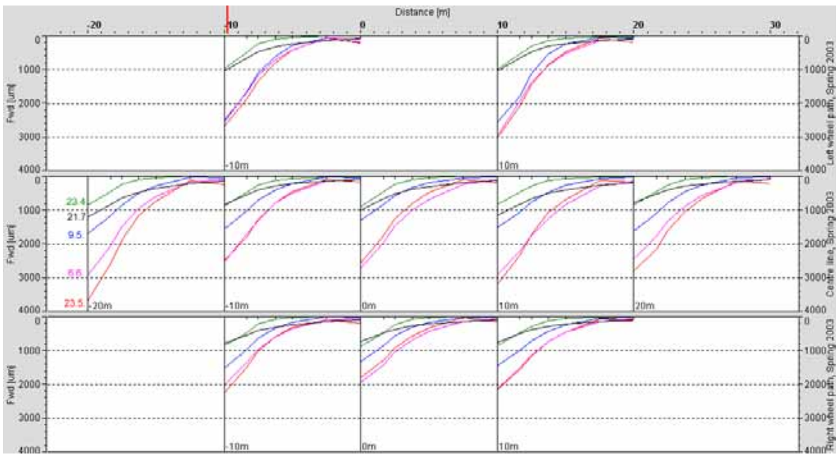

Figure 68. FWD deflections bowls measured at the 50 kN load level on left wheel path (top), center line (center) and right wheel path (bottom) at the Kemijärvi Percostation in spring and summer 2003.

A summary of the moduli values back calculated from the FWD test results from Kemijärvi is presented in appendix 1. The better condition of right wheel path, for instance, can also be seen in figure 69 in which the moduli values back calculated from the FWD results of June 6th 2003 are presented. The moduli values of each layer are mostly bigger in the right wheel path than in the left wheel path or centre line. The figure also shows that increasing the load level had an increasing effect on the moduli values of the combined wearing course and base layer. Deeper the moduli values are roughly the same.

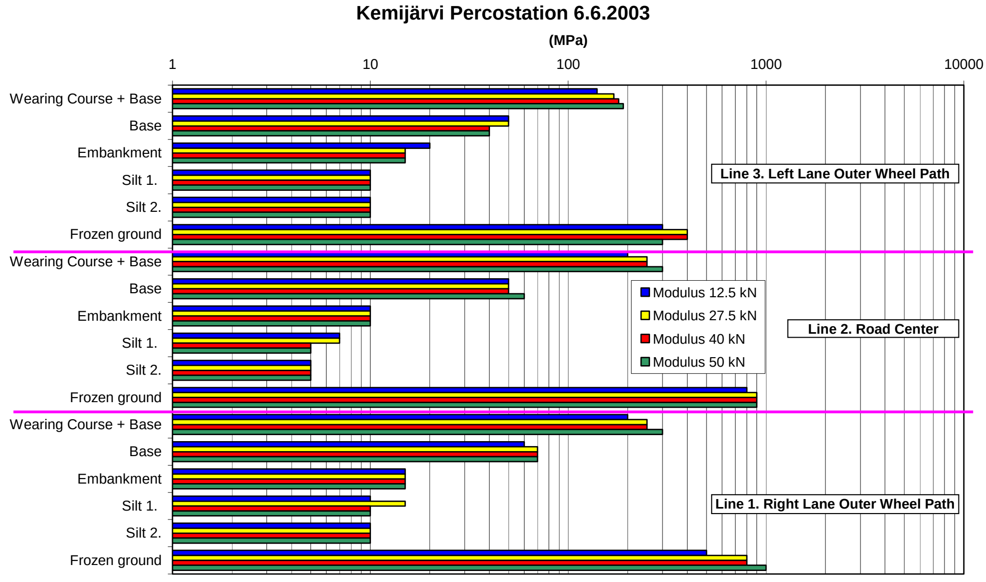

Figure 69. Back calculated moduli values at Kemijärvi Percostation in June 6th on left wheel path, centre line and right wheel path. More back calculated moduli values are presented in appendix 1.

8.3.2 Ängesby FWD results

At the Ängesby Percostation FWD surveys were done three times in 2003. The effect of using different load levels was tested, as in Kemijärvi, but this time the load levels were 26 kN, 38 kN, 50 kN and 68 kN. Figure 70, which summarizes the results of these surveys, shows that, as in Kemijärvi, there were also no major differences in the shape of the deflection bowls at different load levels only the absolute deflection values rose as a function of a load. When comparing the deflection values obtained from different load levels during the spring thaw period with the 50 kN deflection values from July 23rd, which represents a normal “summer value” from a standard 50 kN load, this summer deflection fits between the deflection bowls measured using 26 kN and 38 kN loads.

However, when the Ängesby deflection bowls are compared with the Kemijärvi deflection bowls, major differences in the deflections from the outermost geophones can be seen. In Kemijärvi they have remained very small, even in summer, while in Ängesby the deflection values have clearly increased when the frost thaws and they have also increased as a function of load level. In summer, the maximum deflection values from the outermost geophones were as high as 500 µm indicating that the subgrade was really weak as the Percostation results also indicated. This demonstrates that the Ängesby road structures, perhaps thanks to a MESA treatment, are spreading loads over a much wider area than the structures in Kemijärvi.

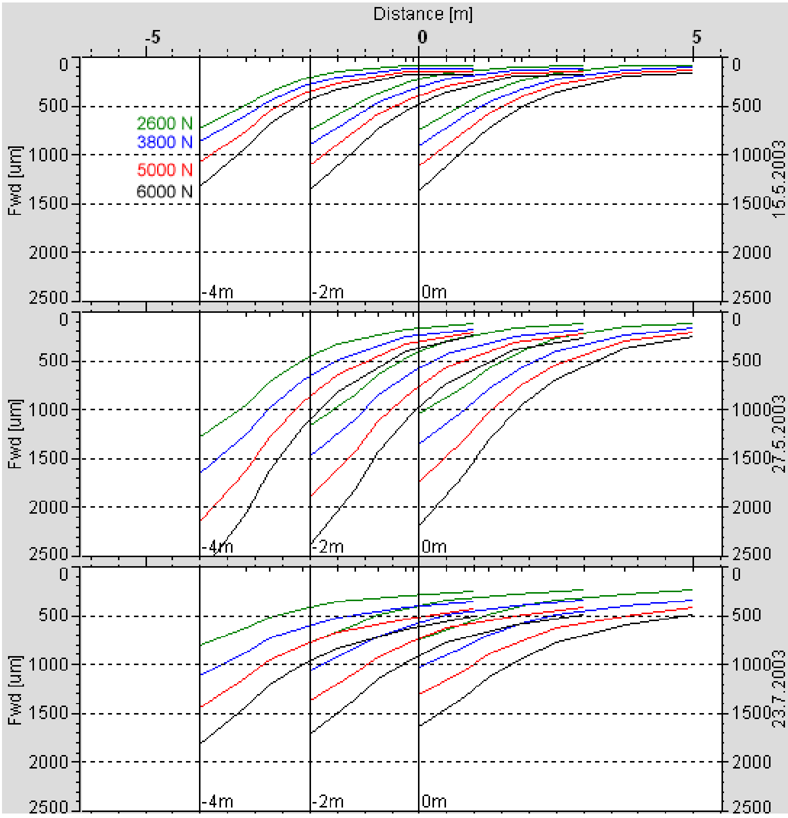

Figure 70. FWD deflection bowls measured at four load levels at the Ängesby Percostation in the right wheelpath in spring and summer 2003.

Figure 71 presents deflection bowls from 50 kN loads at the Ängesby site. The figure shows that the maximum deflection values, quite surprisingly, do not increase during the spring thaw period in the road centre or left wheelpath. This can be also explained by the MESA treatment of the base course. But in the right wheel path the maximum deflection during the weakest period on 27.5.2003 was greater than 2000 µm while after it had dried it was less than 1500 µm. This can be explained, as in Kemijärvi, in that fully loaded vehicles are using the right side of the road and the structures did not have enough time to recover from the loads. In the road centre the road structures are thicker and that is why deflections are not so high. In summer 2003 the deflections in the right and left wheel paths were roughly on the same level.

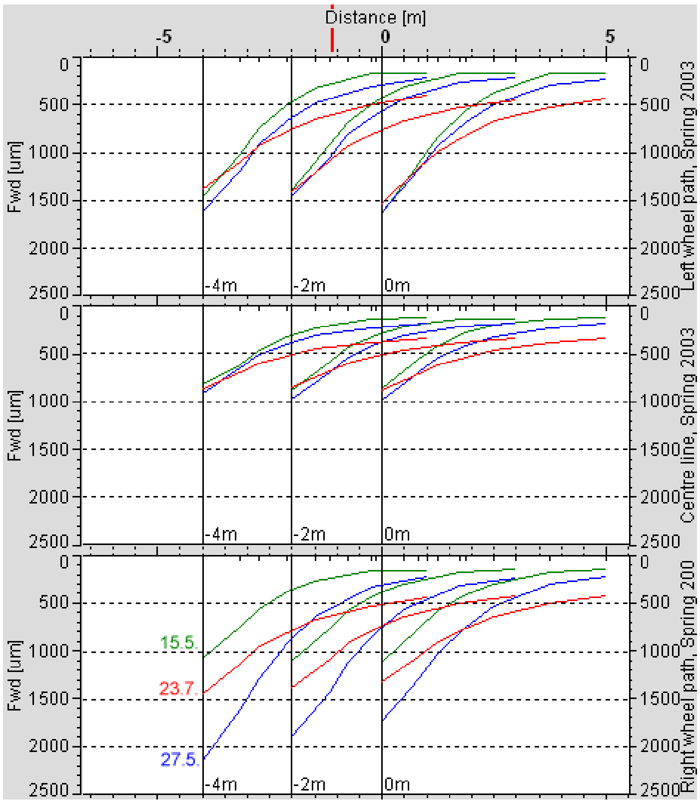

Figure 71. FWD deflections bowls measured at a 50 kN load level in the left wheel path, centre line and right wheelpath at the Ängesby Percostation in spring and summer 2003.

8.3.3 Kuorevesi FWD tests

In Kuorevesi, the FWD measurements were done three times during the spring and summer of 2003 (22.4, 8.5, 15.8). FWD tests with different load levels were also made. However, due to a very soft surface the first two FWD measurements mainly failed and the results were not good enough so that they could be used in a detailed analysis. However some conclusions could be drawn from the maximum deflection values measured at different times. Figure 72 shows that during the weakest period the road was weakest on the left side (right side in the photos) and in the road centre. On the right side, which was located on the embankment side where the probes were also installed, the deflections were hardly greater than in summer. The center line deflections show that during the thaw weakening period the deflections were higher before the Percostation (-20 – 0 m) where the road was also on embankment while in the summer the bearing capacity was better in that section.

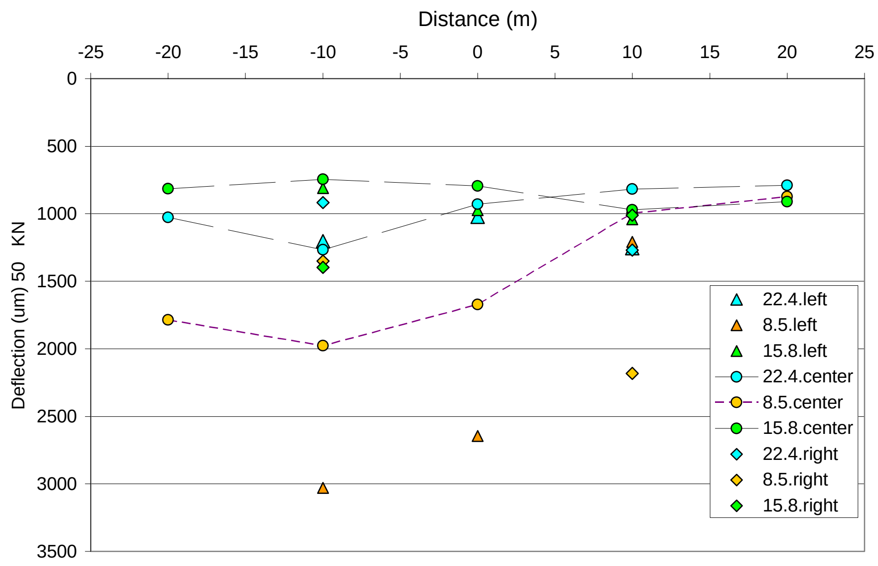

Figure 72. Maximum deflections at the Kuorevesi Percostation during the spring thaw period (22.4.2003 and 8.5.2003) and in summer 2003 (15.8.2003).

8.3.4 Koskenkylä FWD results

In Koskenkylä the bearing capacity during the spring thaw period was monitored in 2001 and 2002 and the results have shown that the road was weakest when the water susceptible sub base layer was thawing and had high dielectric values (see Saarenketo et al. 2002a). In the Roadex survey, FWD surveys were done twice: the first measurement was done on 23.5.2003 when the 1.1 m probe measured thawing values and the second measurement on June 6th when the road had completely thawed (see figure 54). This time the surveys were done using different load levels as in other Roadex test sites.

One of goals of the Roadex II survey was to compare the effect of heavy loading on pavement strain and to test if load restrictions had an effect on the deflection values. This could be done at Koskenkylä by comparing the average maximum deflection values measured in the left lane, which was being used by loaded gravel trucks, with the average maximum deflection values in the right lane, which was being used by the empty gravel trucks. The results from each survey point measured on May 23rd are presented in figure 73. The figure shows that the trend is the same in both lanes but the absolute values are always higher in the left lane. Because the difference was greater at higher load levels, a comparison of the difference in the average deflections between the two lanes at each load level was calculated and the results are presented in figure 74.

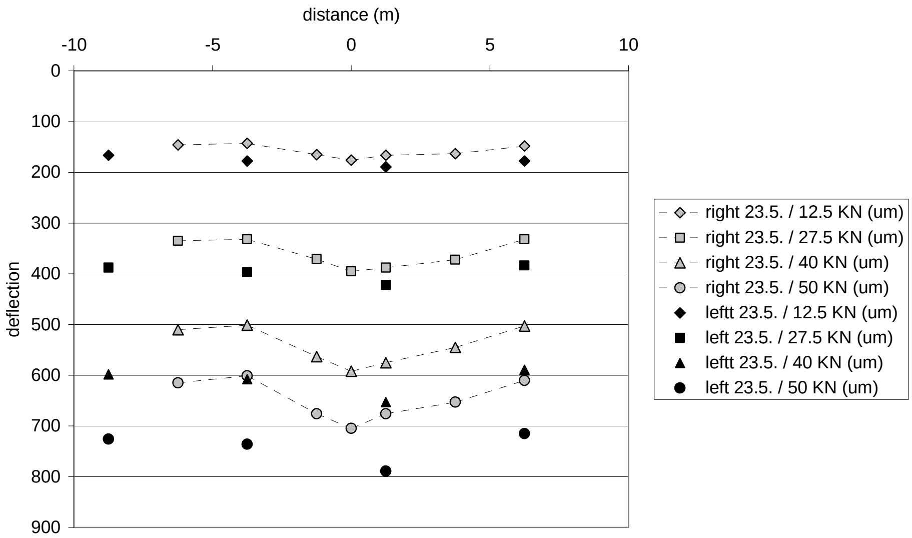

Figure 73. Comparison of FWD central deflection values from the right lane (empty gravel trucks) and left lane (loaded gravel trucks) measured at Koskenkylä Percostation on 23.5.2003.

The results from this figure demonstrate that the average difference between the heavily loaded lane and lightly loaded lane was more than 100 µm during the spring thaw period but the difference decreased at lower FWD load levels. On June 6th the difference at the 50 kN load level decreased to 80 um but was about the same at a 12.5 kN load level. These results indicate that on the paved roads the bearing capacity is poorer and the recovery times are longer in the lanes that heavily loaded trucks are mainly using. This data further verifies that, if the unbound layers have problem materials, load restrictions are a useful tool for protecting the pavement during the spring thaw period.

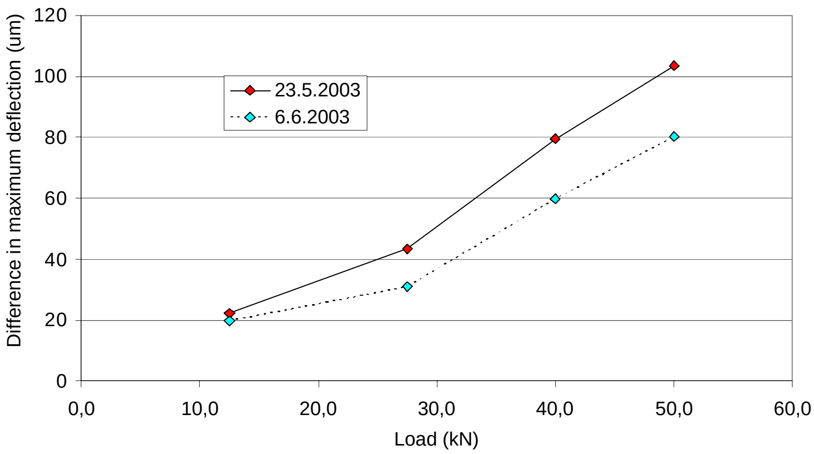

Figure 74. Difference in average deflection values between left lane (loaded trucks) and right lane (unloaded trucks) at the Koskenkylä test site on May 23rd 2003 and June 6th 2003 at different FWD load levels.

8.3.5 Effect of reduced load levels on the maximum deflections on gravel roads

In order to evaluate the effect of different load levels on the maximum deflections and whether this knowledge could be used to define load restriction values the following calculations were made. Figure 75 presents the effect of load level on the magnitude of maximum deflection by calculating the ratio of maximum deflections from different loads. These calculations were based on measurements made in the road centre at the Ängesby, Kemijärvi and Kuorevesi Percostation test sites and in every case; the value used for comparison was the maximum deflection from the 50 kN load. The deflection ratio values, which are presented in light colours, were measured in summer 2003 and the deflection ratio values presented in dark colours were measured in spring 2003 (see label in figure 75).

The figure presents some interesting features. First of all, the deflection ratio from Kuorevesi and Kemijärvi is above the 1:1 line presented in the graph. This means, for example, that if the axle loads are reduced during the spring thaw period by 50 %, the maximum deflections will not be reduced by 50 %. For instance, a 40 kN load in Kuorevesi on the May 8th caused nearly as high a maximum deflection as a 50 kN load at the same time (approximately 95 %). On the other hand, during the summer the corresponding deflection ratios from Kuorevesi, Kemijärvi and Ängesby were lower than the spring ratios and in Kuorevesi and Kemijärvi they were mainly below the 1:1 line. This can be explained as a hysteresis effect whereby the stiffness of the unbound material is higher when the material is drying compared with the stiffness values when it is wetting (see figure 11). The results show that the effect of a reduced load level on the maximum deflections or bearing capacity during the spring thaw period cannot be directly calculated from the results of deflection measurements obtained in the summer. The other interesting feature in figure 75 is that while the ratios of the reduced load levels in Kemijärvi and Kuorevesi were linear and parallel to the 1:1 ratio, the results from Ängesby showed that when load levels are increased the maximum deflections will be reduced even more than was expected at that load level. This can be explained by the use of MESA treatment in Ängesby, and if so, it demonstrates the benefits of the material treatment in strengthening sections with spring thaw weakening problems.

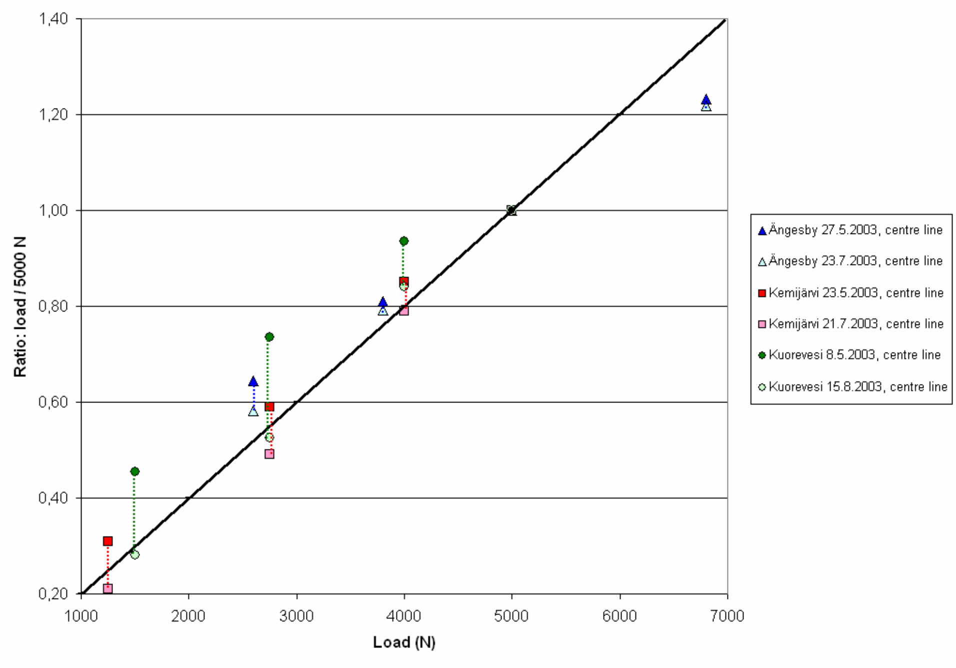

Figure 75. Ratio of maximum deflections on road center at Ängesby, Kemijärvi and Kuorevesi Percostation in spring and summer 2003. Black line represents 1:1 correlation line.

8.3.6 Kemijärvi and Kuorevesi DCP tests

The DCP tests conducted at the Kemijärvi and Kuorevesi test sites during the spring of 2004 produced very useful information concerning how the frost is thawing under the gravel road and how the stiffness of the road structures and subgrade soil changes throughout the spring thaw period.

It should be stated that the moduli values calculated from the DCP test results are not directly comparable with the moduli values calculated from the FWD data. The FWD provides dynamic moduli values while DCP moduli values are based on the shear strength. The DCP moduli values however provide a good view of the relative stiffness of the road structure and subgrade at different depths and locations in the cross section profile.

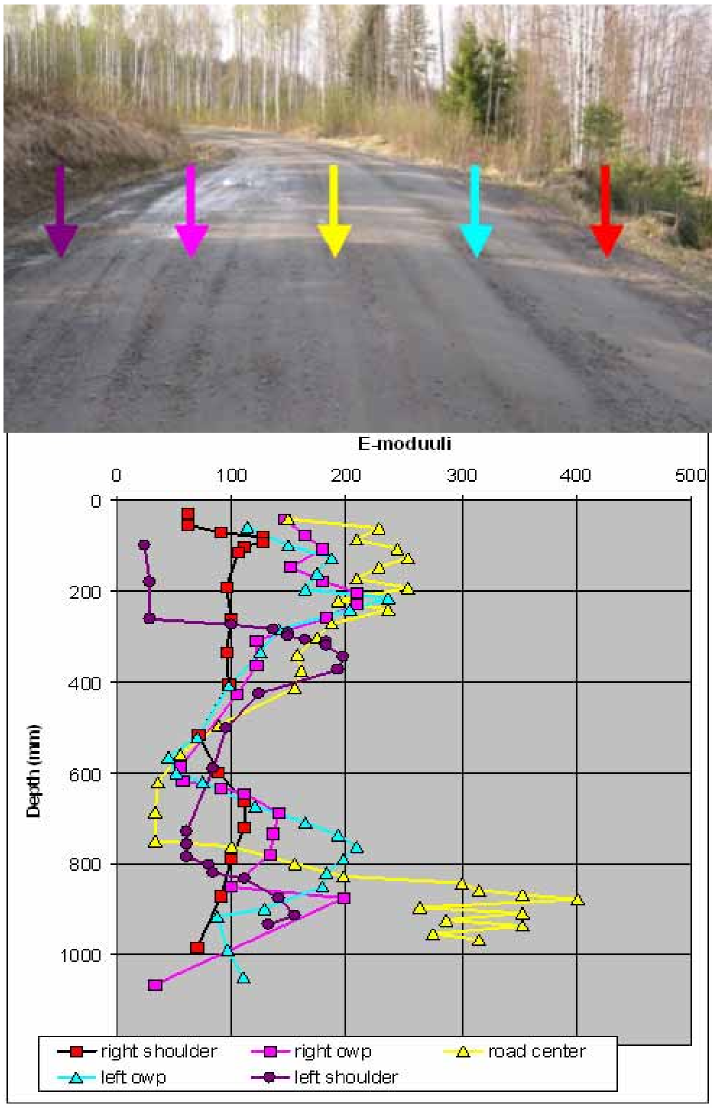

Figure 76. DCP profiles measured at the Kuorvesi Percostation site on May 5th 2004. A Percostation probe is installed under the right wheelpath.

Figure 76 presents the DCP profiles of the surveys done at the Kuorevesi Percostation on May 5th 2004. Percostation results showed that the 0.7 m probe detected that thawing started at that level on May 3rd 2004. The DCP surveys also show that, on May 5th, a 200 – 300 mm thick "dry crust" layer on the top of road structures had already formed by that time. Below that there was a 300 – 400 mm thick soft layer and the frost had thawed to a depth of roughly 600 – 700 mm. Thawing was deepest (about 750 mm) in the road centre. The effect of solar radiation could also be seen from the data. On the left and shady side of the road which is also located on the upper side of the hill slope the frost had thawed only to a level of 300 – 400 mm while the frost had almost entirely thawed on the right road shoulder which is exposed to the sun.

Figure 76 also illustrates well road shoulder bearing capacity problems during the thawing period. The DCP results show that the dry crust with higher stiffness values has not formed in the road shoulders. On every DCP point those layers just above the thawing frost line were very weak and moist.

Figure 77 presents DCP profiles measured at the Kemijärvi Percostation on May 25th 2004. The survey results show that the frost had thawed to a depth of roughly 900 mm below the road at that time. In the right shoulder, which is located on the Northern side of the road, the upper frost line was at a level of 500 mm while on the Southern side of the road the left shoulder had thawed to a level of 750 mm. The DCP results also support the FWD results, presented earlier, which showed that the right side of the road had higher bearing capacity compared to the left side.

The survey results from Kemijärvi, as in Kuorevesi, also indicate that the road shoulders are very weak during the thawing period. The left shoulder was so weak that the DCP tests could not be done near the edge of the shoulder and, that being the case, the measurements presented in figure 77 were made closer to the left wheelpath.

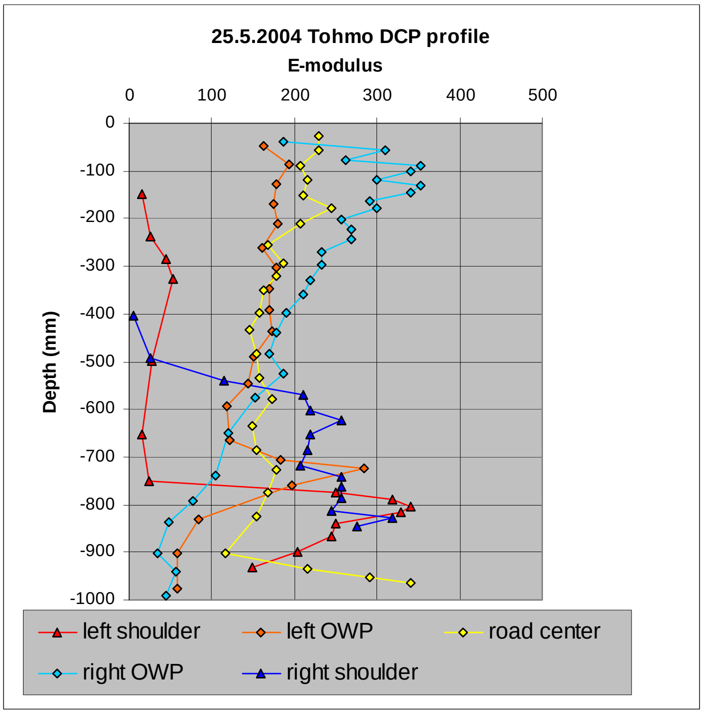

Figure 77. DCP profiles measured at the Kemijärvi Percostation on May 25th 2004.

Figure 78 presents changes in DCP moduli values at different parts of the road cross section through contour maps. The contour map shows that, on April 29th 2004, the left shoulder had thawed to a depth of 850 mm (see figure 79) while the thawing level was at 350 mm in right shoulder. The road structures were weakest on May 6th 2004 when the subgrade started to thaw and the water released from the thick ice lenses had penetrated the road structures. After that period the top part of road started to dry and a dry crust started to develop first on the right side of the road and later on the left side of the road, which heavy trucks were using. The stiffness of the road structures was uniform on the road cross section not until July 1st 2004.

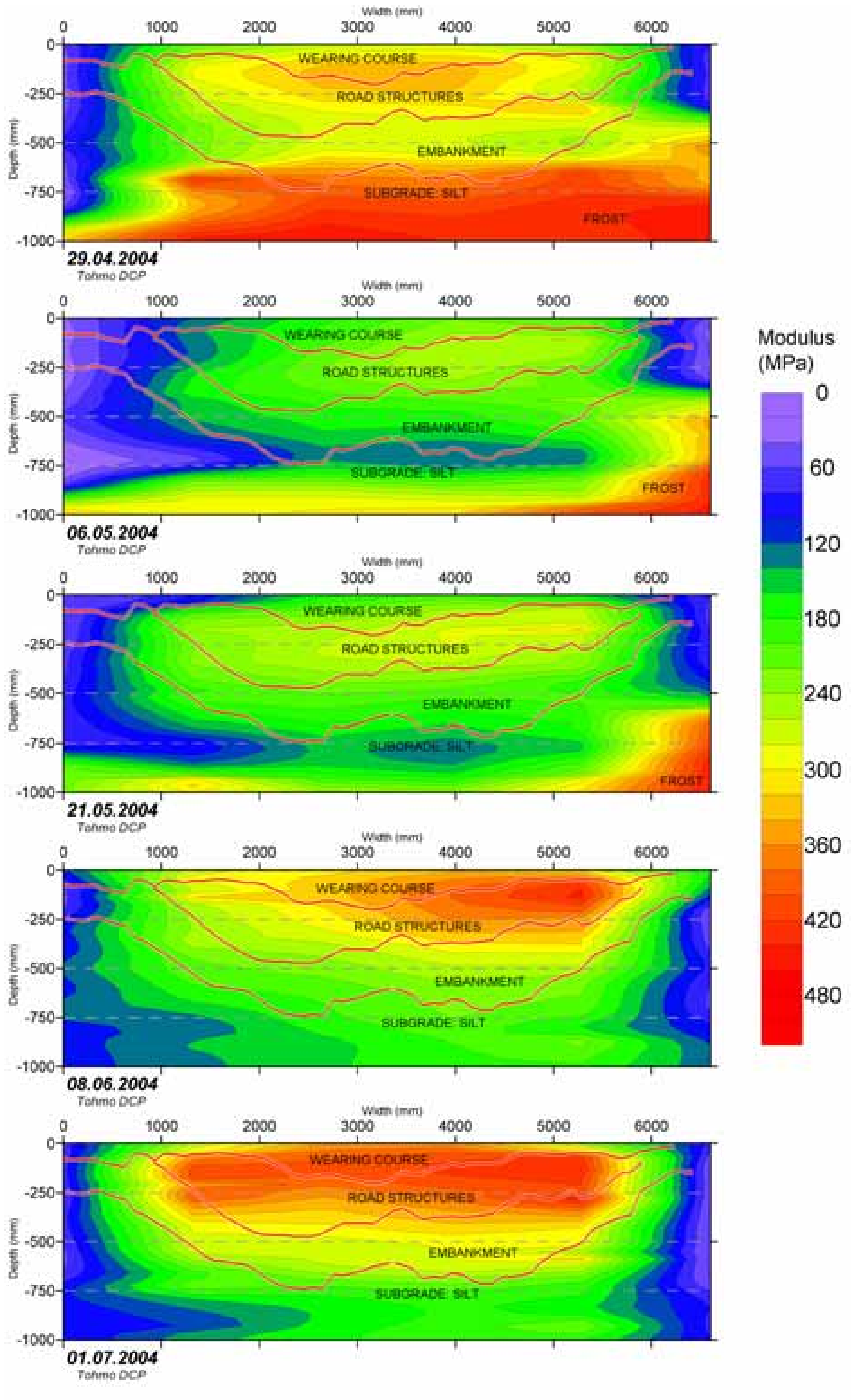

Figure 78. Contour maps of the moduli values calculated from the DCP results obtained during the spring thaw period in 2004 at the Kemijärvi test site on the 0 m point. It should be kept in mind that during the thawing period the thaw settlement was about 400 mm.

The DCP test results also permitted the thawing process to be monitored during the spring thaw period with the results shown in figure 80. The survey data, collected from the left wheelpath, shows that on April 29th 2004 the frost depth was at a level of 600 mm and on May 21st the frost depth was at a level of 900 mm. It should be kept in mind that these DCP results were calculated from the surface of road structures that were settling due to thawing ice lenses. The greatest part of the total frost settlement, about 300 – 350 mm, occurred during May of 2004. Due to water being released from the ice lenses, the layers just above the frost level were always the weakest. The whole road structure was at its weakest point just after the frost had completely thawed on June 8th 2004.

Figure 79. A weak left road shoulder in South side of the road in April 29th 2003 in Kemijärvi.

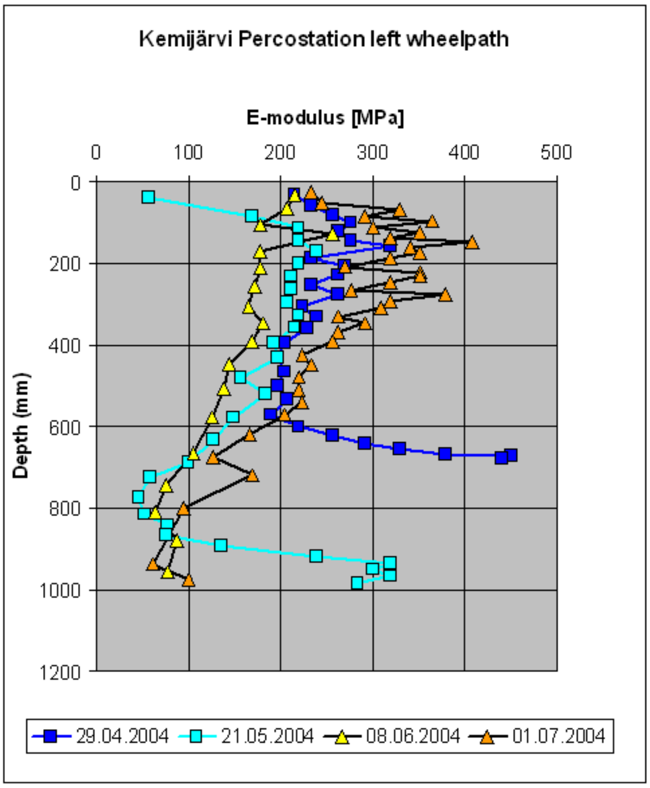

Figure 80. Kemijärvi DCP profiles at Kemijärvi Percostation left wheelpath in spring and summer 2004.

8.3.7 Full scale loading tests

Full scale tests were conducted on the Kemijärvi and Kuorevesi Roadex test sections, in spring 2003, using maintenance trucks owned by the Finnish Road Enterprise. The trucks were loaded with water tanks (figure 81) in order to obtain the maximum axle weights allowed in Finland. In Kuorevesi, the changes in dielectric value and electrical conductivity were monitored during each truck pass using a high speed data logger owned by the Technical University of Tampere. In Kemijärvi the changes were only monitored visually from Percostation central unit.

Figure 81. Full scale loading test done at the Kemijärvi Percostation test site using a maintenance vehicle. Behind the truck an area where water is being squeezed to the road surface can be seen.

<u>Kemijärvi loading test results:</u>
In Kemijärvi the truck made 10 passes on the right lane using a relatively slow speed of 10 – 20 km/h. After these initial passes the road began to fail and tests were stopped. The damage could be observed as cracking in the wheelpaths as well as water pumping through the road structure to the road surface (figure 82 left). At the same time the road became very soft in damaged sections. Another area, where the water was being forced to the road surface, was a wide frost heave shear crack zone in the road shoulder (figure 82 right).

Figure 82. Cracking and water pumping in the wheel paths (left photo) and water pumping through a longitudinal frost crack in the road shoulder (left photo) after ten passes of a fully loaded maintenance vehicle.

<u>Kuorevesi loading test results:</u>
Figure 83 present changes in dielectric values during the full scale loading tests at the Kuorevesi test site in May 15th, 2003. At that time the Percostation indicated that the frost had just started to thaw at 0.8 m level. During the test, 12 passes were made using different speeds from 10 km/h up to 39 km/h. The sampling speed was 1000 measurements / second. During the data processing at Technical University of Tampere (Nuutti Vuorimies) all of the data were scaled according to distance, which is helpful when trying to compare the changes in electrical properties at different speeds and different axle configurations.

The results in figure 83 show that close to the surface, at a depth of 0.15 – 0.2 m, the dielectric value was decreasing under the wheel load and after each pass. This shows that trucks are compressing water from the structure and/or that the structure has become looser. The effect of dynamic loading as an increase in pore water pressure can be seen clearly in the middle figure, which presents the results from the 0.5 m probe. There are high peaks under the driving axle and dual tandem axles and immediately after the truck has passed the dielectric value is on a slightly higher level and then slowly decreases to the original level. At a depth of 0.7-0.8 m there were no major changes in dielectric values. The reason for this is that, at that time, there, most likely, was still some ice present in the soil, which kept the materials stiff. Another possible explanation is that dynamic truck loads did not affect the volumetric water deeper in the soil or very close to the frost level.

Electrical conductivity was also monitored during the loading tests and the results were very similar to the changes in dielectric value. After the loading test, at a depth of 0.4 m electrical conductivity increased 30 microS/cm from a starting level of 190 microS/cm and at a depth of 0.5 m it increased 15 microS/cm from a starting level of 120 microS/cm. These results show that the mobilization of colloids from the clay particle surface to the free pore water still took place during the dynamic loading. At a depth of 0.2 m there were only relatively small changes and at a depth of 0.7 m no changes could be detected.

A transverse rutting profile of the road was also monitored before and after the loading tests and figure 84 shows clear deformation of the road surface especially in the outer wheelpath. The rut depth in the outer wheel path after six truck passes was about 1 cm.

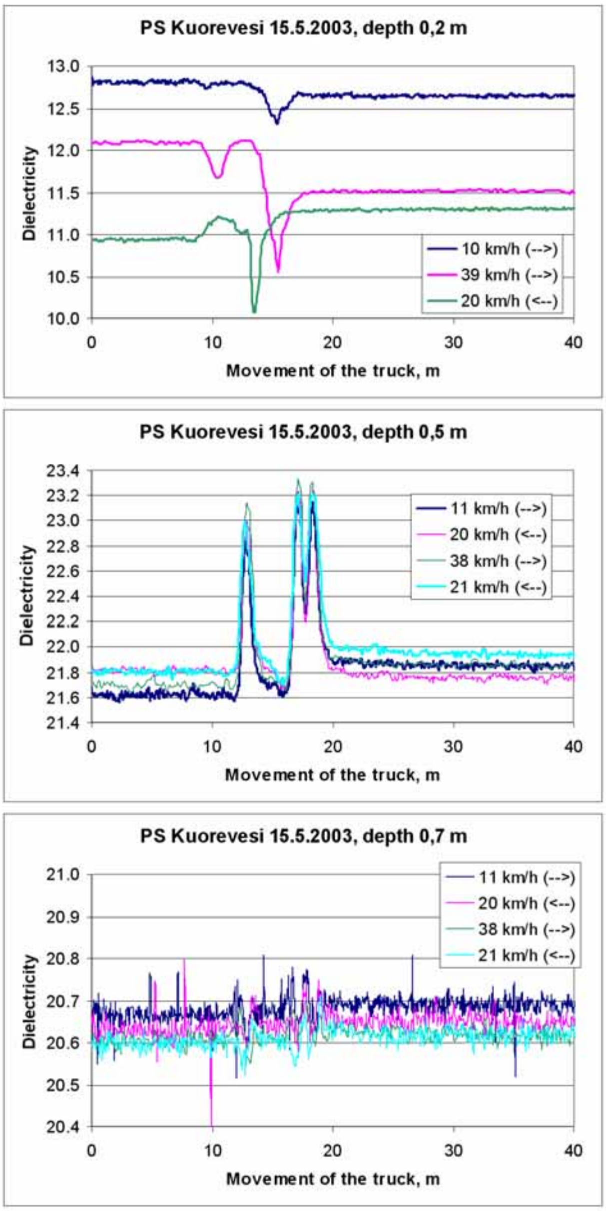

Figure 83. Changes in dielectric values as a result of changes in volumetric water content during full scale loading results at Kuorevesi Percostation 15.5.2003. The top figure presents the probe at 0.15 –0.2 m, the figure in the middle presents the survey results at 0.5 m and the lower figure at a depth of 0.7-0.8 m. Figures were prepared by Nuutti Vuorimies from TUT.

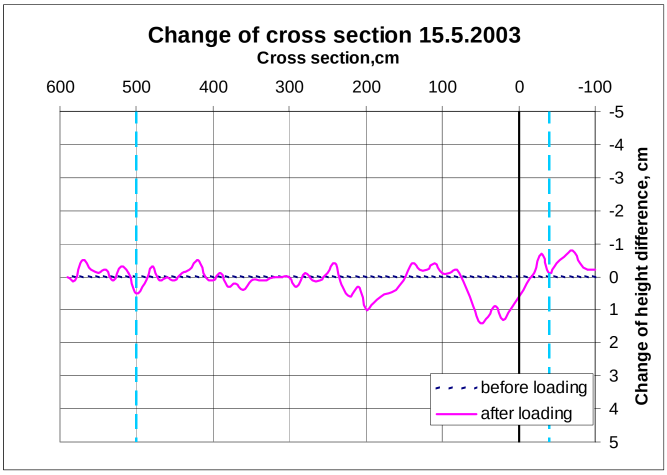

Figure 84. Profilometer results measured from the Kuorevesi Percostation before and after the loading tests on 15.5.2003 (data provided by Nuutti Vuorimies).

<u>Koskenkylä loading test results</u>

The results from the full scale loading tests at Koskenkylä in spring 2001 (Vuorimies et al. 2002) present typical behaviour of both good quality and problematic unbound materials during the spring thaw. Figure 85 presents changes in dielectric value in problematic sub base material at a depth of 0.55 m when two trucks travelling close to each other passed over the probe. Dielectric value, which also represents changes in volumetric free water content, increased after each axle passed. After second truck had passed it took 18 seconds for the value to return to the original level.

Figure 86 from the tests published by Vuorimies et al. (2002) presents the effect of axle load and truck speed on the dielectric value of a good quality base material and poor quality sub base material. The survey data clearly shows that good quality base course behaves elastically in that the dielectric values drop to the normal level immediately after the axle pass at each test speed. While the problem sub base material does not behave elastically. At low speeds, 20 km/h or less, with a longer loading time the dielectric value raises much higher and recovery time is much longer compared with the test results from speeds of 40 km/h or higher.

Figure 87 presents the changes in electrical conductivity during a truck pass. The figure shows that during the thawing period electrical conductivity increases slightly after each axle pass. This can be explained in that, after freezing, colloidal particles are released from clay surfaces to the pore water.

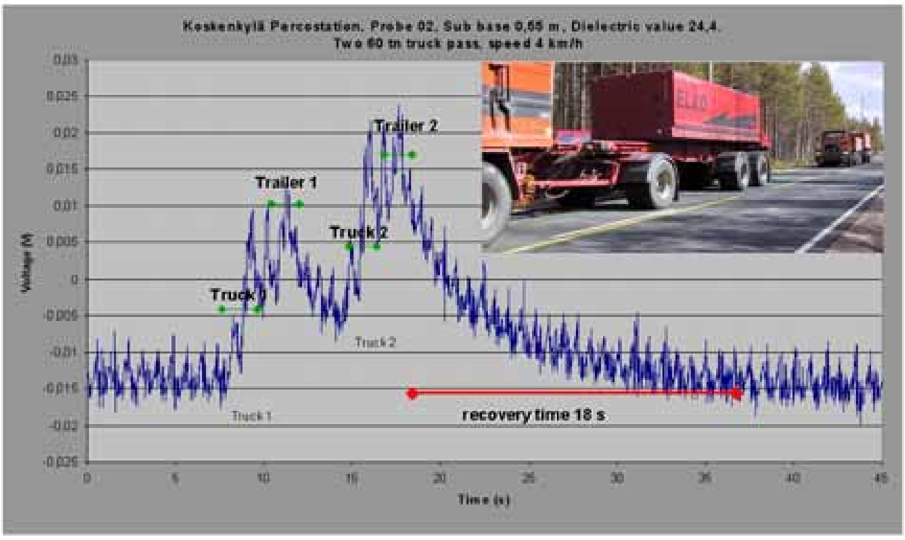

Figure 85. Dielectric response (change in voltage) of a base course at a depth of 0. 55 under the loads of two 60 ton truck and trailer combinations.

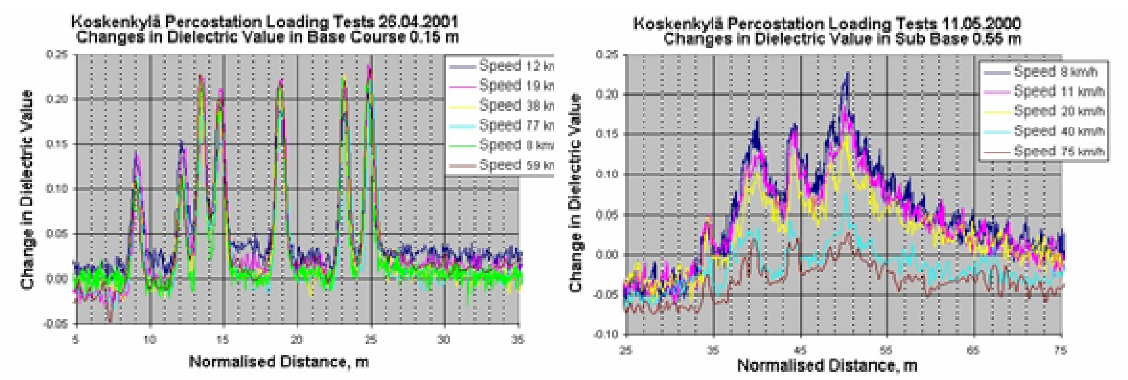

Figure 86. Dielectric response of a good quality base course (left) and poor quality sub base (right) under the load of a 60 ton truck and trailer combination passing at different speeds (Vuorimies et al. 2002).

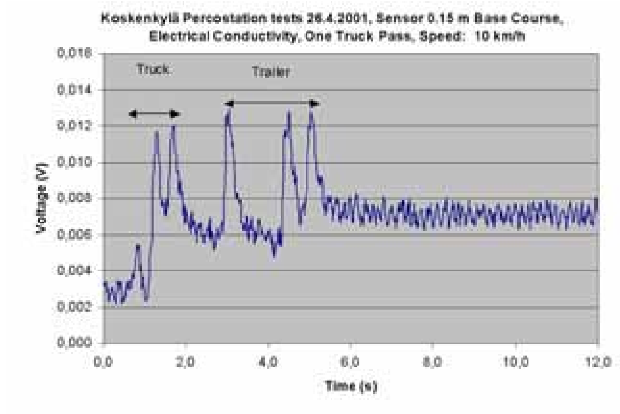

Figure 87. Effect of a 60 ton truck and trailer combination on the electrical conductivity of a base course immediately after it has thawed on 26.04.2001 (Vuorimies et al. 2002).

9 Summary of Roadex field test results

The Roadex II project has managed to collect new and valuable information, which has helped researchers to understand, describe and model the mechanisms of spring thaw weakening. One of the new methods used in the project was the Percostation technique, which through its monitoring of changes in dielectric value, electrical conductivity and temperature could provide new information regarding seasonal changes. The Percostation results from Garvault demonstrated the effects that both freeze-thaw cycles and heavy rains can have in increasing moisture content in the base course below the pavement. The Percostation results, from the gravel road sections in Ängesby, Kuorevesi and Kemijärvi in combination with observations of the surface condition showed that the surface thaw weakening phase, when the road surface becomes plastic, can be seen as increased electrical conductivity. After the surface thaw period the next critical period, according to the Percostation data, was when moisture susceptible road structures with a high moisture content (high dielectric value) started to thaw. In this phase permanent deformation of the structures can be seen as high rut depth or alligator cracking could be observed on roads that heavy vehicles were using. The last critical period started when the segregation ice (ice lenses) on the top part of subgrade started to thaw and, as the Ängesby Percostation data showed, during this period when the ice lenses thaw the road is almost literally floating on water. At this time, when heavy vehicles travel the road section at short intervals, giving no time for recovery, water is forced upwards into through the road structures which can then, as a result, become plastic.

The data obtained from the Percostation during the freezing period in the fall provided information on how freeze-thaw cycles affect moisture content and the freezing mechanism of road structures and subgrade. These results have been used to make new models of the ground freezing.

The results from frost heave survey done on the Roadex test sites were quite surprising and further served to illustrate the complex nature of the frost heave process. In Ängesby the highest frost heave was measured in the road shoulders, while in Kuorevesi the frost heave was greatest in the road centre and in Kemijärvi the road structures were acting like a piston, pushing up and down through the road shoulders during the frost heave and thaw period. There were also quite major changes in the maximum frost heave values in Kemijärvi (350 mm), Kuorevesi (250 mm) and Ängesby (160 mm) even though the subgrade soils was basically the same. These differences can be explained in that in Ängesby the ground water level was higher than in Kemijärvi. In Koskenkylä, where the road was paved, almost all of the ice lenses, causing 40 – 60 mm frost heave, developed in the frost susceptible sub base. It is also worth noting that in every gravel road test section the frost heave in the road structures was about 50 – 60 mm.

Frost thaw settlement and DCP surveys clearly showed the effects of solar radiation during the spring. Thaw settlement always started on the southern side of the road or in a place exposed to sunshine. This places stress on paved roads especially because differential thaw settlement on a road cross section causes extra strain on the pavement. This was also verified through data collected from the Koskenkylä Percostation site (see figure 66).

The problem with the bearing capacity surveys, made with FWD, on the Roadex tests sites was that both springs, 2003 and 2004, were quite mild in terms of spring thaw problems. That being the case, the FWD results may not represent the worst conditions on the road. However, the FWD data did provide a great deal of valuable information on the stiffness of the road structures during the spring thaw. The FWD deflection analysis, as well as the DCP results from the gravel road sections confirmed the fact that the bearing capacity of the road was worst shortly after the frost had completely thawed. This was in contradiction with the fact that the load restrictions had been removed in both Finland and Sweden before the frost had completely thawed. On the other hand if road authorities had waited until the period of highest deflections was over there would still have been load restrictions in mid July in Northern Scandinavia. For instance in Ängesby Sweden, close to Luleå, in 2003 frost completely thawed in early July. If the FWD is to be considered for future use as tool for monitoring spring thaw weakening and making decisions regarding load restrictions then a more detailed analysis of the moduli values obtained from the top layer would be required.

Analysis of the FWD data collected using different load levels also provided valuable information. These results showed that during the spring thaw period load levels that are about 50 % of the maximum 50 kN loads are producing deflections similar to 'summer values' measured with a 50 kN load and therefore do not cause any problems on gravel roads. However additional studies on this subject are still needed especially concerning the effect of repeated loads. The FWD comparison tests showed that there are no major changes in the deflection bowls after four cumulative loads compared to the deflection bowl of a single load. Figure 88 shows that after a single load the magnitude of maximum deflections measured from a 50 kN load are, for the most part, slightly greater than after cumulative loading of 12.5kN, 27.5kN, 40kN and 50kN. This demonstrates that road structures have been compacted by cumulative loading.

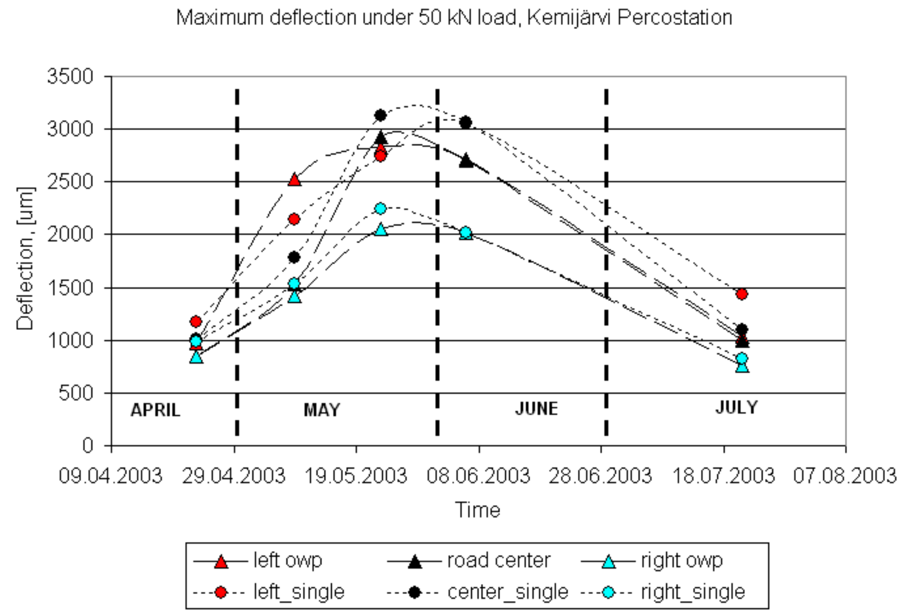

Figure 88. Average maximum deflections under 50 kN load after cumulative loads and a single load at Kemijärvi Percostation during spring and summer 2003.

The average maximum deflections under 50kN load at Kemijärvi, Ängesby, Kuorevesi and Koskenkylä Percostations in spring 2003 are presented in figure 89. The presented deflection values were calculated as an average value of 2 – 5 FWD points measured from the lane that fully loaded vehicles are using. It can be seen that the weakest phase during the spring thaw was in May and early June. It is also clearly visible that the road structure at the Kemijärvi Percostation was the weakest although the measurements were not done in Ängesby and Kuorevesi at the same time. However the smallest summer deflection values were also measured at the Kemijärvi Percostation. Naturally the average maximum deflections during the spring thaw period were the smallest in Koskenkylä Percostation where the road is paved (see figure 89).

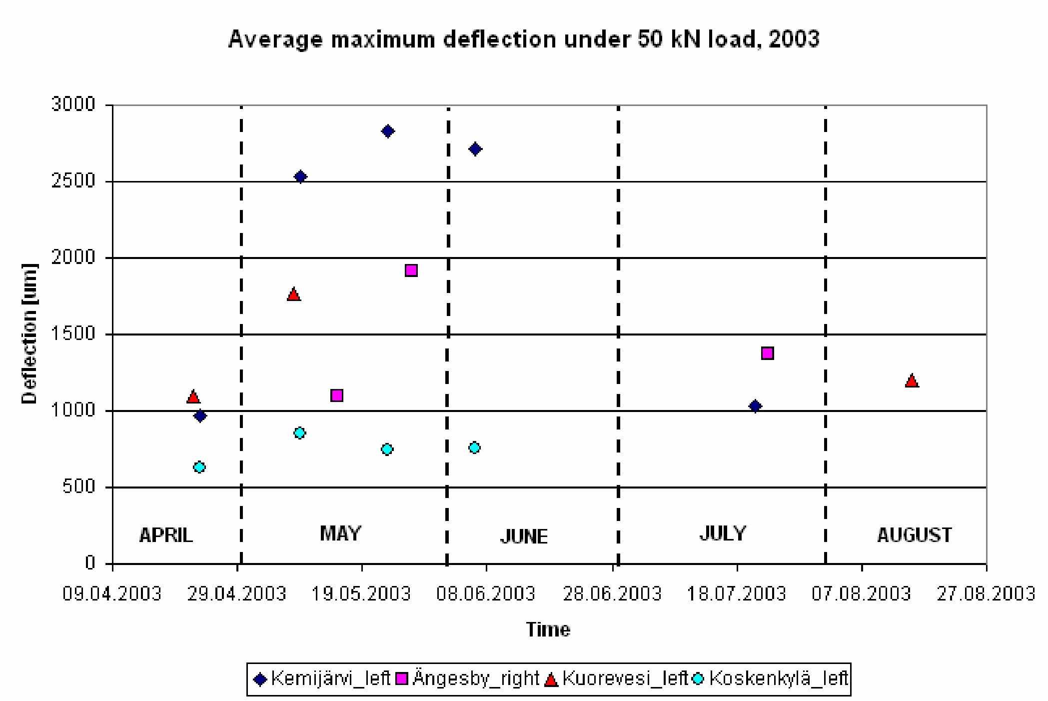

Figure 89. Average maximum deflection under 50 kN load after cumulative loading in Kemijärvi, Ängesby, Kuorevesi and Koskenkylä Percostations during spring and summer 2003. Measurements were made from the lane that fully loaded vehicles are using.

The FWD deflection bowl comparisons from the Ängesby and Kemijärvi test sites also produced very interesting information regarding the effect of a treatment agent on load distribution. In Kemijärvi, the deflections radius was very small while in Ängesby, most likely thanks to MESA treatment, the radius was much greater and the load was distributed over a wider area even though the subgrade was much weaker in Ängesby. There was also no visible damage at the Ängesby site.

The DCP test, of all the bearing capacity survey methods tested, proved to be the best at surveying the stiffness of road structures and the subgrade soil beneath. It is cheap and relatively fast method and can easily be used on different parts of a road cross section. In the case of extremely weak structures it is not possible to detect small stiffness changes with DCP. However the DCP method reveals clearly the weakness of a structure, a good example during spring thaw period was the road shoulders at the test sites which were so weak that the cone penetrated several hundred millimetres with one blow.

The DCP tests done at the Kemijärvi test site also showed how much faster the frost thawed on the southern shoulder of a gravel road in open areas. The greatest benefit of using the DCP technique to monitor spring thaw weakening is that it is possible to evaluate if the top structures are stiff enough to carry a truck load and, in that case, restrictions can be removed even though the subgrade is still very weak. Figure 90 provides a comparison of the moduli values, back calculated using Elmod 5.0 software from the FWD data, and a contour map of the DCP results measured on cross section 10 m before Kemijärvi Percostation. This illustrates that even though the absolute values may not be at the same level the trend is exactly the same and that the road is much weaker on the left side than it is on the right side.

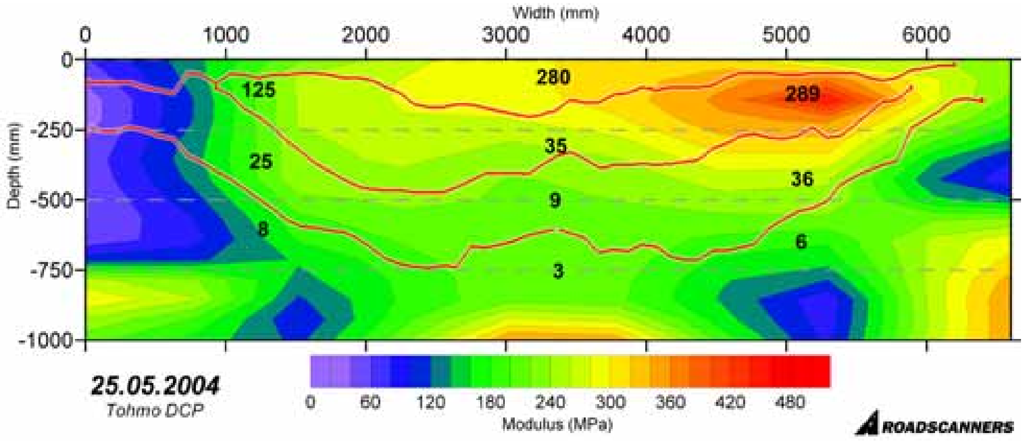

Figure 90. Comparison of moduli values calculated from the DCP results obtained 25.05.2004 with the moduli values calculated from the FWD data (50 kN load level) measured on 25.05.2004.

Figure 91 presents graphs of the surface modulus (E0) calculated from FWD data measured on cross section 10 m before Kemijärvi Percostation. The graphs of the surface modulus show that the subgrade is still frozen at a depth of about 1m in both the left and the right wheelpaths. The subgrade is in a very weak condition above and beneath the frozen layer as can be seen in figure 91. However, in the DCP profiles this thin frozen layer could not be detected so clearly. In road center the frozen layer in the subgrade is thicker at a depth of 1m, which can be seen both in the DCP profile and in the surface modulus graph (see figs 90 and 91).

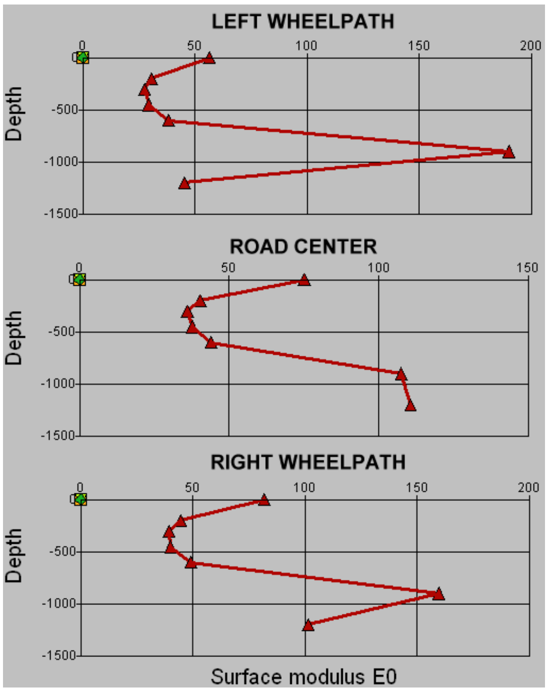

Figure 91. Surface modulus measured from cross-section 10m before Kemijärvi Percostation on 25.5.2004.

Figure 90 shows also other interesting feature that could be seen in all test sites, i.e. the road was in all test sites much weaker in that lane that trucks were using with full loads. The results from the paved road in Koskenkylä showed that this is also problem for paved roads and that by reducing axle loads this effect can be reduced. This together with full scale loading results indicates the idea of recovery time might have much bigger role in the future when modelling spring thaw weakening and impact of heavy vehicles to the road performance (see figure 92).

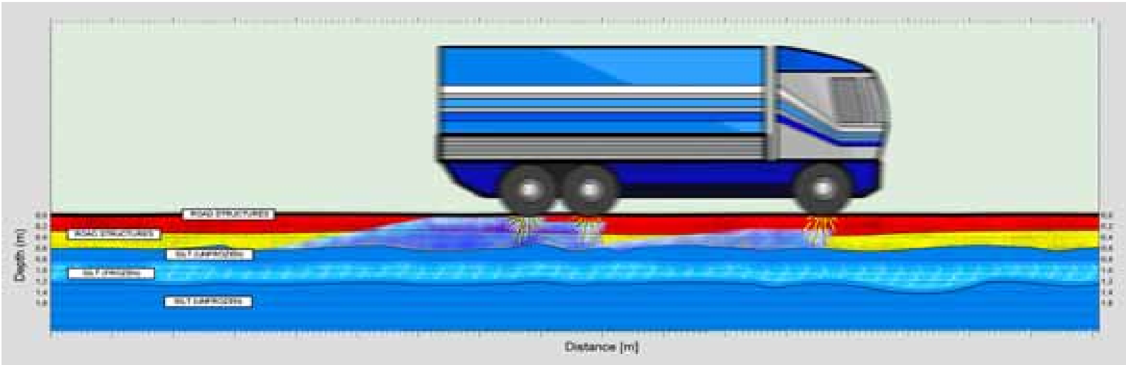

Figure 92. A schematic graph of the truck axle loads forcing melt water from the ice lenses up to the road surface. After such a pass the road requires a recovery time in order to prevent plastic deformation of the road structure.

Full scale loading tests on the gravel road test sites showed that, during the early phases of the subgrade thawing period, water was being forced to the road surface and severe deformation and cracking could be found in the road surface even after just ten standard truck passes. Dielectric value and electrical conductivity measurements indicated that a standard axle has a measurable effect on pore water at least to a depth of 50 cm. The test also revealed that, close to the frost level, the structure, while under a dynamic load, did not display any changes in the electrical properties.

One interesting observation from the full scale tests done earlier at Koskenkylä was that slower truck speeds, which amount to longer periods of loading times, caused higher pore water pressure in materials susceptible to permanent deformation while with good quality unbound aggregates the length of the loading period did not affect the response.

Tests related to electrical conductivity indicate that colloids released from clay mineral surfaces into the pore water can have a great effect on the forces between the mineral particles during the thawing period. Because this is one of the main mechanisms of the permanent deformation process more research should be devoted to this subject. This characteristic could play a key role in the future development of new sensor techniques for real time road condition monitoring.

10 A new proposal for spring thaw weakening phases

The Roadex II spring thaw monitoring results showed four altogether different time phases for spring thaw weakening that have such unique features that they should be classified separately. They occur in a chronological order but the need of load restrictions, for instance, at each phase is strongly dependent on the increase, or lack thereof, in moisture content and stiffness of the road during the previous period. The four classes presented here are the 1) freeze-thaw cycles, 2) surface thaw weakening, 3) structural thaw weakening and 4) subgrade thaw weakening phases. A common factor in all of these classes is cryo suction. A potential fifth category with similar bearing capacity problems could be the autumn heavy rain season, although during this season, freezing is not a factor in the weakening process. Figure 93 summarizes these phases based on the Percostation data from Roadex's Kuorevesi test site.

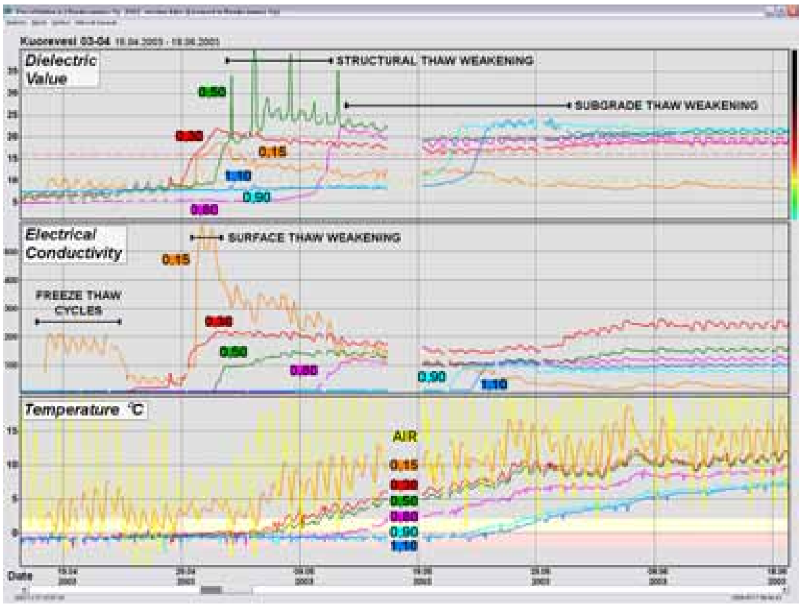

Figure 93. Spring thaw phases at Kuorevesi Percostation in spring 2003.

10.1 Freeze thaw cycle phase

The first phase affecting spring thaw weakening is the phase of freeze-thaw cycles in late fall, when the road surface freezes during the night or for a few days and thaws when the air temperature becomes warmer. Several freeze-thaw cycles in a short period of time during the fall cause major problems in Scandinavia. The force of cryo suction during a repeated freeze thaw process causes water to flow within the structure close to the road surface Continuous freeze-thaw cycles act as a pumping mechanism ending in a situation where the wearing course becomes plastic or, in the case of paved roads, the base course under the pavement become saturated with water and, as such, susceptible to permanent deformation. The rutting mode in this phase is mode 1 (see Dawson and Kolisoja 2005). One factor affecting the severity of the following spring thaw weakening is the number of freeze-thaw cycles that occurred during the fall and how shortly after these cycles the road begins its final freezing process.

In Scotland, the main problem is not spring thaw weakening but repeated freeze-thaw cycles during the winter. A good example of this freeze thaw mechanism can be found in the Percostation test data from Roadex test site at Garvault (see chapter 8.1.2) where after each freeze-thaw cycle the moisture exceeded the critical level for permanent deformations to occur under heavy truck loads.

10.2 Surface thaw weakening phase

Following winter the first phase is the "surface thaw weakening phase". Its severity depends on the road condition before winter, but above all on the weather and traffic conditions when the road surface starts to thaw.

During this phase colloids are released into the pore water from the clay mineral surfaces and this easily causes material to become plastic. This phase could be seen as high electrical conductivity values at Percostation sites and could be further verified with the photos taken from the sites. This critical phase normally takes from 6 – 14 days and after that the road surface becomes dry if there are no heavy rains.

If the weather is dry, load restrictions are not normally needed on gravel roads during this phase. This phase can be very critical for paved roads, especially weak ones with surface dressing pavement, which can easily crack. Load restrictions should be considered if the base below the pavement has segregation ice or it is wet due heavy rains.

Figure 94. Surface thaw weakening on road 19778 in Kemijärvi Finland. Photo has been taken on 19.04.2004 when the frost had thawed to a level of 120 – 140 mm.

Freeze-thaw cycles do not always have damaging effects on road structures. Especially on gravel roads, during the spring thaw weakening season, cryo suction during frost nights causes water to flow towards the road surface and because frost nights are generally followed by sunny days, solar radiation causes evaporation and thus the surface part of the road structure dries fast.

More critical than freeze-thaw cycles in gravel roads, during the surface thaw weakening phase, is rainfall. Continuous rainfall prevents the gravel road surface from drying and so it remains wet, slippery and plastic and in such a case the forecast for the next phase of the spring thaw weakening will be bad. The rutting mode in this phase is also Mode 1.

10.3 Structural thaw weakening phase

The second phase, "structural thaw weakening", starts when the upper frost line has thawed deeper than 15-20 cm but has not yet reached the subgrade soil. Because the subgrade is still frozen, the FWD deflections are still quite small. The moisture content in a road depends on rainfall and how well the drainage functions. During this phase a great part of the thaw settlement takes place if the road structure has frost susceptible material. If there is a significant amount of heavy traffic, the excess water, under repeated wheel loads, surges towards the road surface producing conditions with a high likelihood of causing of plastic deformation (rutting mode 1) of the road structure. Major differences in the level of frost thaw settlement can be found in a road cross section this is mainly due to differences in the amount of solar radiation that a particular side of the road is exposed to.

The structural thaw weakening phase can be the most critical phase of the spring for some roads. The data collected from the Koskenkylä site revealed a 20 cm layer of poor quality unbound material at a depth of 45 – 65 cm to be the only source for bearing capacity problems during the spring thaw period. The survey results from the Roadex gravel road tests sites also indicated that a relatively large part of the frost heave occurred in the road structure itself (40 – 60 mm) and thus weakened the road during the thawing period.

The need for the load restrictions during the structural thawing period depends primarily on the condition of the road when this phase starts. If the road surface is soft after the surface thaw period, restrictions are needed, but if the surface is stiff and there are not too many heavy vehicles using the road then it remain open to heavy vehicles.

10.4 Subgrade thaw weakening

The subgrade thaw weakening phase begins when the upper frost line reaches the subgrade soil. The severity of this phase is dependent, on the one hand, on the amount of maximum frost heave due to segregation ice in the subgrade soils and, on the other hand, on the stiffness of the road structures when subgrade thawing begins. A third, and equally important, factor is the weight of heavy vehicles and frequency of these loads since they determine the recovery time.

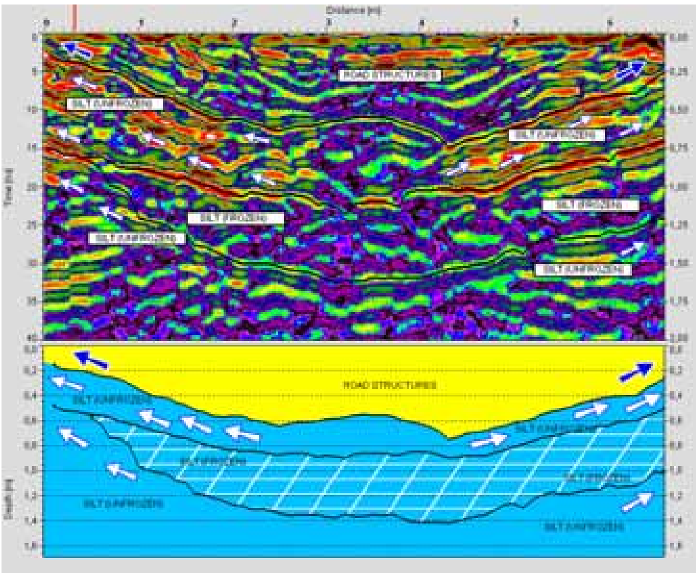

Figure 95. GPR cross section measured at the Kemijärvi test site in May 2004. The GPR profile reveals very wet silty material between the road structure and frozen ground. Reflection structures also indicate plastic flow towards the road shoulders. Wet silty material can also be found under the frozen soil.

When the subgrade thaw weakening phase begins load restrictions should finally be implemented especially on gravel roads with known spring thaw problems and roads with weak subgrade soils. This is especially the case if the road structures are not dry and stiff enough. Load restrictions should be applied to paved roads only if the increase in rutting has been exceptionally high. Rutting mode is in this phase is mode 2 (see Dawson and Kolisoja 2005).

Subgrade thaw weakening can be divided into two sub phases and figure 95 presents a typical GPR cross section profile measured during the early part of the subgrade thaw weakening phase at the Kemijärvi test site. At that time, about 20 cm of the subgrade had thawed and the melting ice lenses in combination with the embankment load and heavy vehicles cause high pore water pressure in the soil, which causes it to become plastic. The wet soil is squeezed out from under the road structure onto the roadsides and road shoulders (see figure 15) and to the middle if structures are thin. All of these aforementioned processes cause the road to widen.

The FWD deflection data obtained from the Roadex sites indicated that the road was weakest during the last part of the subgrade thaw weakening phase when the frost had completely thawed. However, if deflection data were the primary criteria for the timing of load restriction in Scandinavia, the restrictions would have not been removed until late June – mid July. But the restrictions in Scandinavia are removed much earlier because the road structures above the subgrade are thick enough and have become dry enough and stiff enough after thawing has started. However if the road structures are wet and there are many heavy vehicles using the road at close intervals severe pavement damage may appear.

11 Spring thaw weakening site classification

11.1 General

In the long term, the most sustainable solution for managing spring thaw weakening sites is to repair or strengthen the sites in such a way that the problems will not be repeated. When selecting the optimum repair technique, the problem is that the spring thaw damage mechanisms are complex and as such different spring thaw weakening sites require different rehabilitation solutions. Figure 96 presents spring thaw damage classification results from the problem roads in the municipality of Kuorevesi in the Keski-Suomi Road Region of Finland. The figure clearly illustrates that, even in a small area, there can be several reasons for the damage and thus one standard strengthening method cannot be applied to every case.

The following general classification and description of each problem site is based on the Finnish classification system (see chapter 4.4), which can also be used as for basic problem diagnostics and selecting the optimum rehabilitation method. A brief description of the rehabilitation structures is also provided. A classification method based on the topography and drainage condition is discussed in the Roadex II drainage report by Berntsen and Saarenketo (2005).

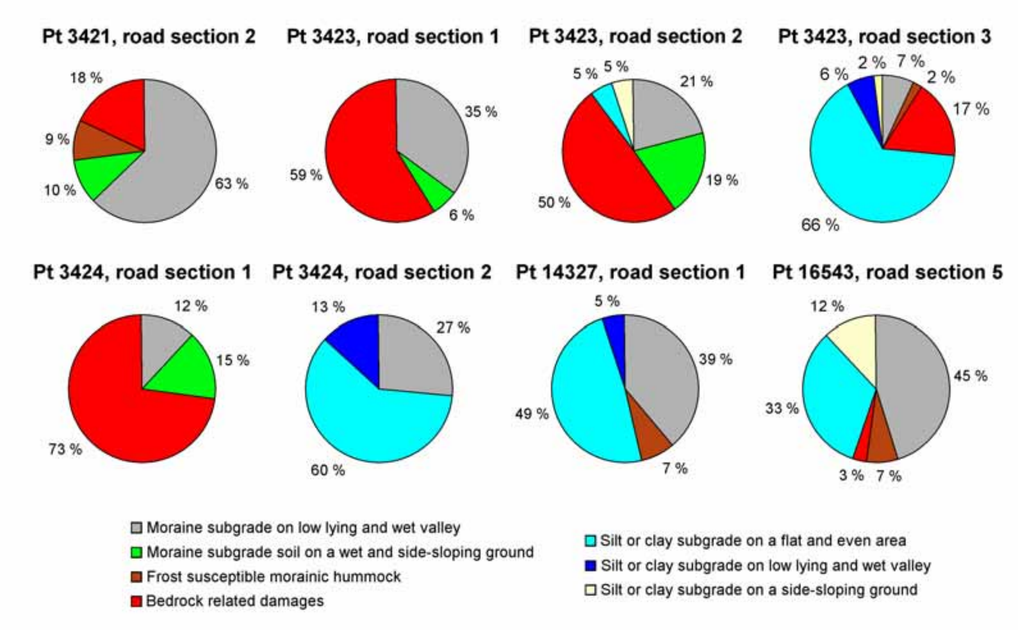

Figure 96. Spring thaw damage classification of eight gravel road sections in Kuorevesi, Finland.

11.2 Damage site classification

11.2.1 Moraine subgrade

The spring thaw weakening damage that occurs in moraine (glacial till) areas can be quite different based on whether the road is located in the bottom of the valley, on sloping ground or on a morainic hummock. The damage found at hummock sites is mainly located in the transition zone where the road leaves the embankment and layers are thinner (figure 97). Softening takes place through the cross section. Differential frost heave bumps are often found in these transition zones during the winter. Soil replacement structures are the most suitable for these sites because they do not raise the grade line. Basic structures have also been used successfully (see chapter 11.3). When a damaged road is located in a low lying valley or a flat area, weakening occurs throughout the entire cross section. In these areas the best solutions are always new structures on top of the old road. On transversely sloping ground with a high ground water level most of the thaw damage is located on the upper side of the hill slope. In these sites, when the freezing front penetrates to the ground water level, segregation ice forms and the expanding soil causes frost heave in the road shoulder (figure 98). In the repair design, the drainage on the upper side of the road always has to be improved. The best structures have proven to be new structures on top of the old road (structures 2-3 in chapter 11.3).

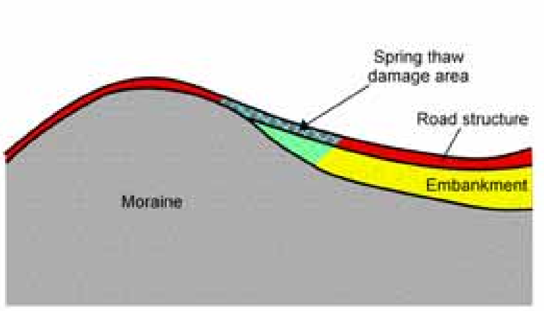

Figure 97. Typical location of spring thaw problem site on a gravel road over a morainic hummock.

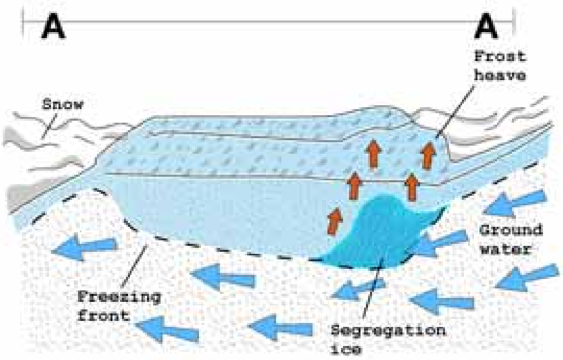

Figure 98. A schematic figure of the development of spring thaw damage on a road located on transversely sloping ground in an area where ground water is close to surface.

11.2.2 Peat

When the spring thaw damage classification system was developed and the first network level surveys, using GPR and FWD techniques, were done in Finnish Lapland and the Vaasa Region a surprisingly large amount of spring thaw damage were found in areas where the road was resting on peat. This was somewhat of a surprise because it was believed that peat would have been acting as insulation for the road. However, additional and more detailed analyses of damaged road sections showed that most road sections were located in the transition zones where the subgrade changes from mineral soil to organic peat (see figure 99). A special feature of these sites is that the road shoulders are also extremely weak. Strengthening design for these sites has been quite challenging because new structures create additional loads that may further cause settlements. That being the case, steel reinforcements have proven to be a successful option in recent years (see figure 100).

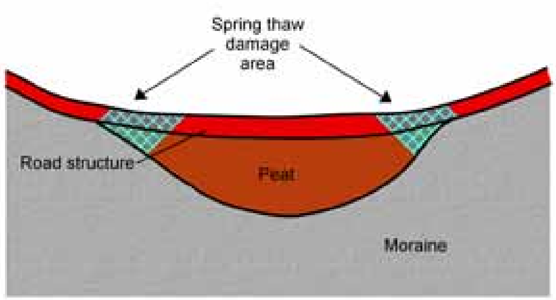

Figure 99. Location of spring thaw damage in road sections resting on peat.

Figure 100. Using steel reinforcement in strengthening a typical spring thaw damaged section on road 955 in Kittilä, Finnish Lapland (photo: K. Niva).

11.2.3 Bedrock

Surprisingly, a large part of the spring thaw damage can also be related to the presence of bedrock. The bedrock problem sites are located mainly on side-sloping ground and the cause of damage is that the bedrock together with frost block the ground water flow and this causes differential frost heave and thaw weakening (figure 101).

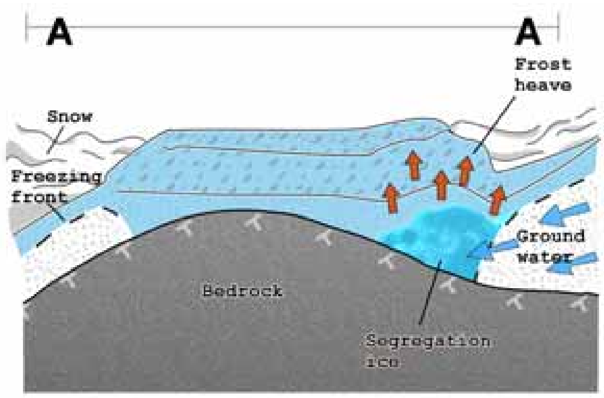

Figure 101. A schematic figure of a road cross section with spring thaw damage problems due to the presence of bedrock.

Figure 102 presents a typical case from road 3424 in Kuorevesi, Finland with bedrock related spring thaw problems. A Road Doctor analysis profile shows the most severe spring thaw damaged section between 560-600 m with class 1 problems every year from 1996-2000 is located between two bedrock peaks. In that section, the GPR data also shows that the frost level is high and that segregation ice lenses are present. Between 780-1000 m, class two spring thaw damage was continuously observed almost every year around the bedrock peaks.

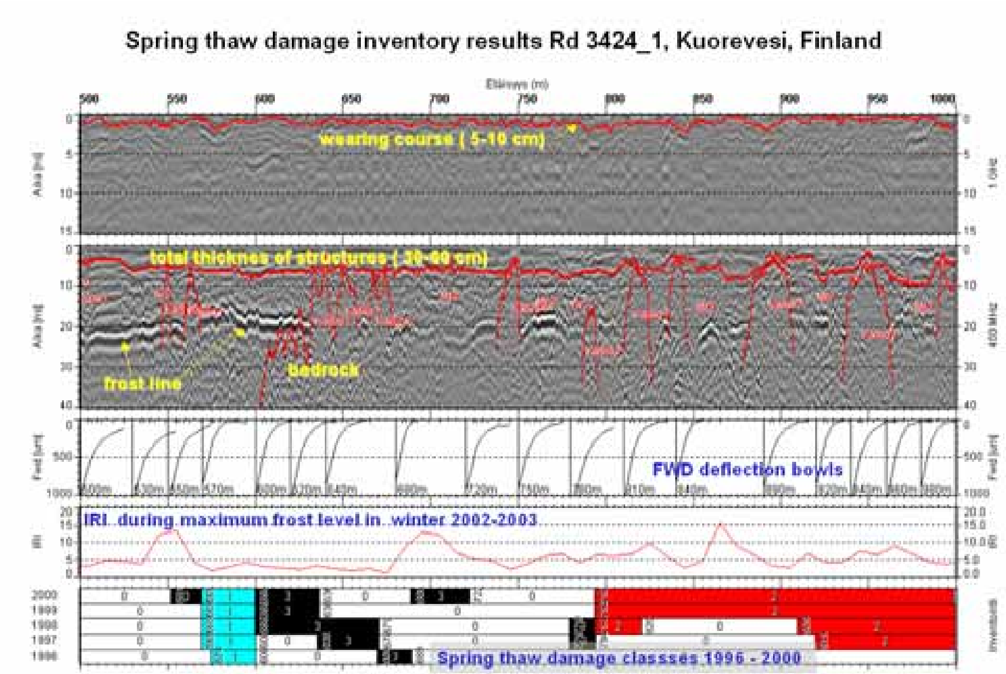

Figure 102. Road survey data, analysed with Road Doctor software, from road section 500-1000 m from road 3424_1 in Kuorevesi Finland. Top GPR profile presents the wearing course, lower GPR profile GPR data down to 3 m presenting total thickness of road structures, presence of bedrock and frost line. Three lowest profiles present FWD data, IRI (10 m mean) data and spring thaw damage history data 1996-2000.

Selection of the optimum repair structure for a problem site with bedrock close to surface have to be evaluated case by case. In many cases the improvement of the drainage and preventing water from flowing into the structures or under the road is the best solution. Soil replacement down to the bedrock surface level has also worked well but it is quite an expensive solution. Norway has successfully used frost insulation structures, which allow ground water to flow under the pavement. In sections with only slight damage, new structures on the top together with drainage improvement have also been working well.

11.2.4 Silt and clay

Silty subgrade, related spring thaw damage, usually causes the biggest spring thaw weakening problems for the road users and owners. These road sections can become nearly impassable to a normal passenger car. Figure 103 present a schematic model, based on several GPR surveys, of a typical cross section of a problem gravel road located on silty subgrade soil. The road structures are thick only below the wheelpaths. This material is mainly mixed wearing course and base course aggregates used to temporarily strengthen the road. Differential frost heave, due to varying road structure thickness, causes longitudinal cracking in the road shoulders and, if the gravel road structures are thin, in the road centre. During the subgrade weakening period, subgrade breakthrough also takes places in the middle of the road. The road has also widened during the spring thaw settlement period and on both sides of the road normally there are 0.5–1.0 m wide extremely weak shoulders with only 0,2-0,3 m thick layers. During the spring thaw weakening period these road can become plastic after only a few heavy truck passes.

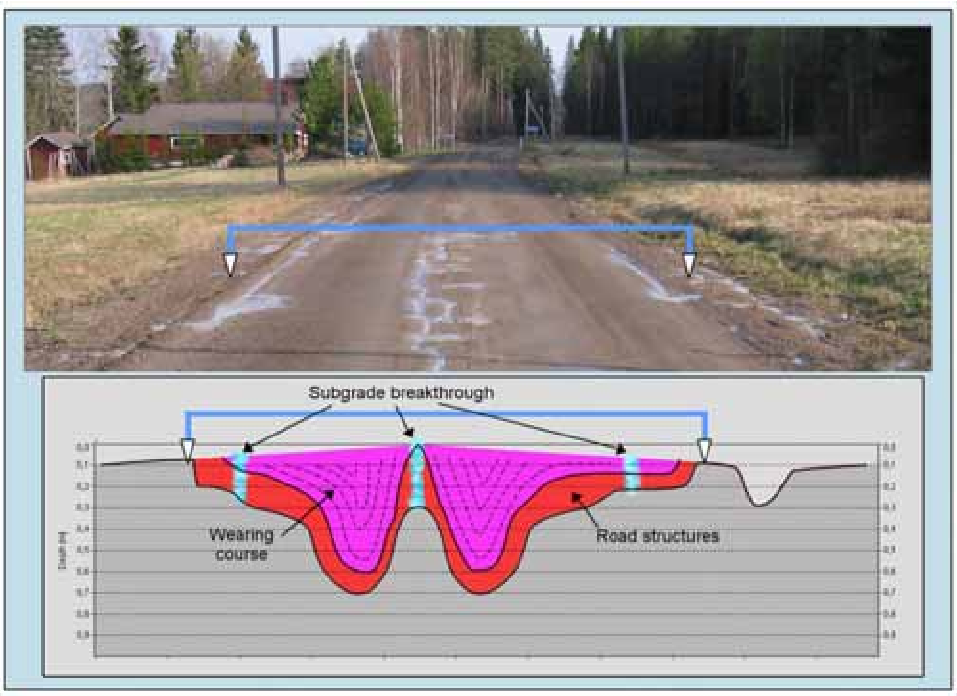

Figure 103. A typical cross section of a gravel road with spring thaw damage problems that is located on a silty subgrade soil.

When selecting repair techniques for spring thaw problem sections located on silty subgrade the key factors to consider are drainage, homogenisation of the road structure, sufficient reduction of the effective stresses on the old road during the spring thaw. In addition is also important not to strengthen the road over the widened road shoulders using standard structures unless they have been repaired first. The best and most economical solutions have proven to be structures 2-4 presented in chapter 11.3.

11.2.5 Others

Other special sites with spring thaw problems can be related to a clogged lateral culvert located on side-sloping ground (see figure 104) and to the gravel road sections where the wearing course has become too thick. The former problem can be repaired by opening or replacing the culvert. A wearing course that is too thick and also has a high fines, and possibly high chloride, content can be treated by removing or replacing it or mixing coarse grained material into it.

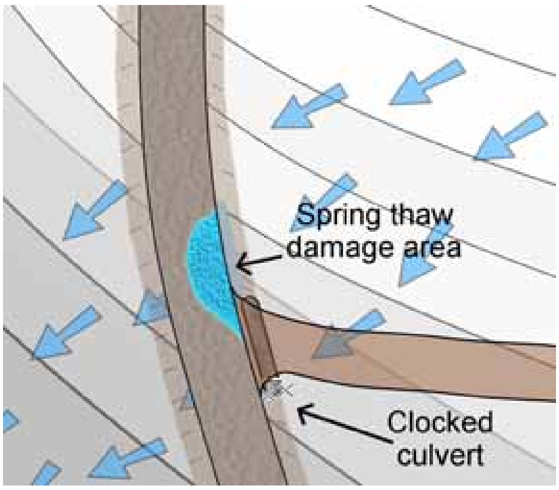

Figure 104. Spring thaw damage area related to a clogged lateral culvert under an access road.

11.3 Spring thaw damage strengthening techniques for gravel roads and paved roads

11.3.1 General

The best and most sustainable solution for managing spring thaw weakening problems is to strengthen and rehabilitate the weak road sections. However this can and should only be done if a road region has enough resources to take measures that will function over the long term. A series of research interviews conducted with road masters in Finland (Saarenketo & Aho 2003) revealed that great number of the sections that receive emergency repairs fail again the following spring. That is why sufficient resources should be allocated to diagnosing problems and designing solutions in these road sections. Major mistakes have also been made when road sections have been strengthened using structures that are too weak these problems become especially apparent if the road is paved afterwards (see figure 105).

Figure 105. Typical damage on a road that has had spring thaw problems when it was a gravel road (see figure 103) and was paved without homogenization of the old structures and without improving the road structures to an adequate level.

Gravel road rehabilitation and strengthening design is quite straightforward when the cause of the damage has been well researched. Basic rehabilitation and strengthening structures will be presented later in this report.

Strengthening design, for paved roads with spring thaw problems and especially those that have surface dressing pavement, is much more complicated. These roads normally have thin structures and generally, when deciding how the pavement structure should be treated, there are no cheap solutions.

However, if funding is not available for strengthening the road structures, the most effective method to combat spring thaw problems on paved road is to improve the drainage system and maintain it in good working order. Different drainage techniques have been reported in great detail in another Roadex report, “Drainage on Low Volume Roads” (Berntsen and Saarenketo 2005). Recently Henry et al. (2005) have also tested different structures for strengthening gravel roads against spring thaw weakening. According to their results only methods that either 1) permanently improved the strength of the top layers or 2) decreased the water content of the upper 300 mm of the road resulted in a significant performance improvement during spring thaw. Geogrid and geotextile separators and trench drains did not provide any significant observable benefits to the roads during spring thaw season (Henry et al. 2005).

Structural solutions that have been used successfully to deal with spring thaw weakened roads in Finland will be discussed in the sections that follow.

11.3.2 Converting a paved road back to a gravel road

If the bituminous pavement in a road section is very bad suffering continuously from problems with potholes, ravelling and rutting and the use of weight restrictions does not help (or if they cannot be used), the cheapest method to reduce high maintenance costs is to convert the road back to a gravel road. During recent years in Finland and Sweden, this measure has been taken on several roads, which have not received funding to make improvements to the structure. During the first few years, these measures received a great deal of negative feedback from the local people but the drivers of heavy vehicles have shown a better understanding of the reasons behind such measures. Although, after some time, the local people seem to have forgotten their initial frustration and accepted the situation. It almost goes without saying that, in general, measures such as these do not bring much in the way of good will towards road authorities. In the Roadex project the road at the Ängesby Percostation site in Sweden is a good example of a road where the problems have decreased following the change back to gravel.

11.3.3 Basic structural options for repairing spring thaw damages on gravel roads

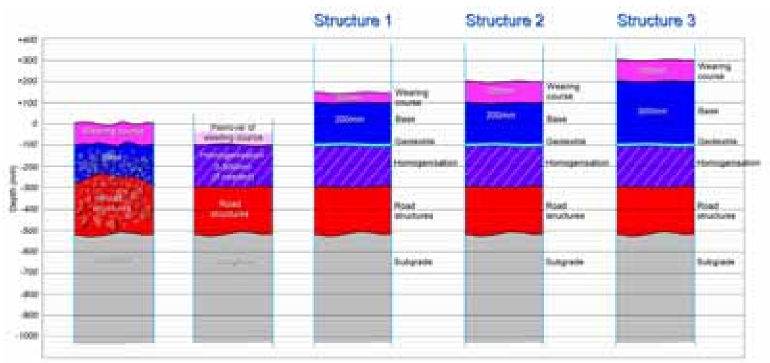

Figure 106. Basic structures 1-3 used in gravel road strengthening projects in Finland. A more detailed description of the structures is given in the text.

In Finland, thanks to increased funding during the last few years, more attention has been given to the strengthening of the gravel roads with spring thaw problems and also to the performance of repaired structures. The basic structural solution, used, in late the 1990´s and early 2000´s, to strengthen gravel roads, was a geotextile (filter cloth) + 200 mm of base course + 50 mm of wearing course. This structure is described in figure 106 as structure 1 but normally this was done without removal of wearing course and without homogenisation. However several reports from the last few years (Saarenketo & Aho 2003, Ryynänen et al. 2003) have stated that this cheap structure might be too weak and that failures following rehabilitation have been quite common. Another observation was that the costs of maintaining a thin (50 mm) wearing course over a 200-300 mm thick unbound base are very high because this layer cannot adsorb enough water through the granular base and it is too thin to hold moisture in dry summer months. That, as such, is why the addition of a 100 mm wearing course has been recommended as a method of repairing such a structure.

However, research concerning the function and life cycle costs of repaired gravel road structures (Aho 2004) suggested that the biggest reason behind the failure of strengthened structures was that the rehabilitated structures were not constructed as thick as the design had called for. If in fact this is the norm and not the exception then more focus should be placed on the quality control of construction procedures.

Figure 106 presents the most popular basic structural solutions that are currently being used to strengthen gravel roads with spring thaw damage problems in Finland. Rehabilitation should normally be started with the removal of most of the existing wearing course material from the road surface. Wearing course material with high fines content should not be left under the new structure but it can be used later for the new wearing course or on the road shoulders. After removing the wearing course, the top 200 mm of the structure should be homogenized (see figure 107) in order to remove boulders and stones and create a homogenous platform for the new structures. Before placing the geotextile (filter cloth) the road should be shaped to proper cross slope and compacted. Geotextile is very useful in the preventing old structures from mixing with the new structures although it can break easily especially on transversely sloping ground and bedrock sites. The base course is laid over the geotextile and compacted (figure 108). The base course thickness is normally 200 or 300 mm, however a structure thicker than 300 mm is used when the spring thaw damage is severe or if the subgrade is weak. Calculations made by Aho (2004) indicate that during the spring thaw weakening period stresses caused by heavy trucks reduce most sufficiently in a 400 – 500 mm thick layer from road surface. Thus the most optimal structure to repair spring thaw damages on gravel roads is a structure that reaches a depth 400 – 500 mm from the road surface.

Figure 107. Homogenization of the top 200 mm of the structure. (photo: T. Ruohomäki)

Figure 108. Placing base course over geotextile. Boulders removed during the process of homogenization can be seen on the road shoulder.

In some circumstances heavier structures are needed to ensure proper functionality of the road. That is especially the case when several spring thaw damages are located in a section of road passing through a low lying valley. In that case the damage is most often related to low vertical alignment of the road and thus strengthening is best to do by raising the grade line using 500 – 600 mm thick new structures (see figure 110 structure 5). Due to the risk of differential settlements it should be carefully considered to use such thick structures when the subgrade is weak and compressible, such as peat or gyttja. In cases of weak subgrade soil, differential settlements can be reduced by using structure 4 (see figure 109 structure 4) in which a part of the aggregate thickness is compensated with steel grid reinforcement. Reinforcement also works well against permanent deformation and against widening of the road. Further to this, the results of the REFLEX project (2002) show that the weaker the subgrade soil is the greater its advantage will be.

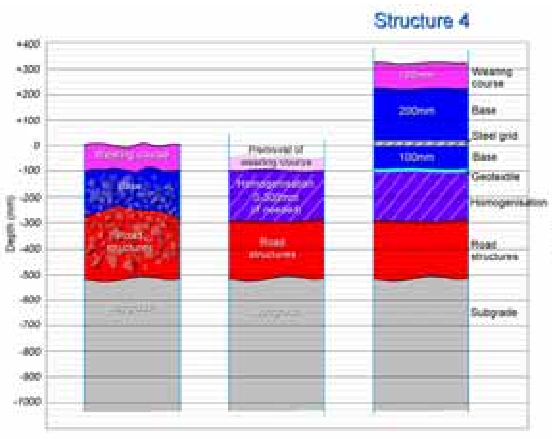

Figure 109. Structural option 4, steel reinforcement.

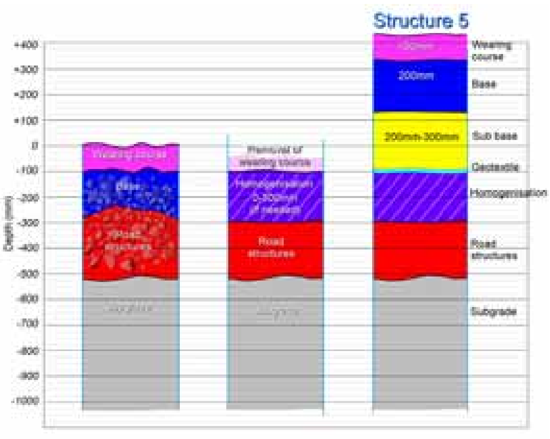

Figure 110. Structural option 5, 500 – 600 mm thick new structures.

When spring thaw damage is severe and difficult differential frost heave can also be found in the same section, in many cases, the only way to solve the problem is soil replacement (for instance structure 6 in figure 111). Because of thick structural thickness soil replacement is, however, quite seldom an economical solution on low volume roads. Although it can be effective to replace soil with frost resistant and water permeable material in cases where bedrock is located close to the road surface and is blocking water.

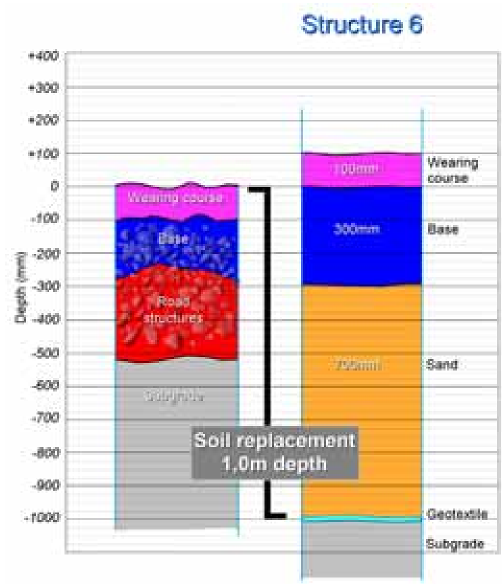

Figure 111. Structural option 6, soil replacement 1 m depth.

Aho (2004) did some calculations regarding the lifetime costs of the standard repair structures for gravel roads and the results verified the assumption that there is not one standard economical structural solution for repairing spring thaw damage. Depending on the prevailing conditions at a spring thaw damage site the lifetime of the structure may be shorter and thus lifecycle costs higher. In the lifecycle analysis Aho used the construction costs presented in table 11 for structures 1 – 6. Lifecycle analysis indicated that if the structures function as expected (normal lifetime) then the cheapest structure is structure 2, which also happens to be the thinnest one having a wearing course thickness of 100 mm (figure 112). Naturally the most expensive one is soil replacement to a depth of 1 m (structure 6).

Table 11. Structural options 1 – 6 and their mean construction costs in Finland. (Aho 2004)

STRUCTURE	COST
Structure 1: **Basic** 50 mm wearing course 200 mm base course geotextile	40 000 €/km
Structure 2: Basic 100 mm wearing course 200 mm base course geotextile	45 000 €/km
Structure 3: Basic 100 mm wearing course 300 mm base geotextile	55 000 €/km
Structure 4: Steel reinforcement 100 mm wearing course 300 mm base steel grid geotextile	70 000 €/km
Structure 5: New structures 500 – 600 mm 100 mm wearing course 200 mm base 200 – 300 mm sub base geotextile	70 000 €/km
Structure 6: Soil replacement 1 m 100 mm wearing course 300 mm base 700 mm filter sand	110 000 €/km

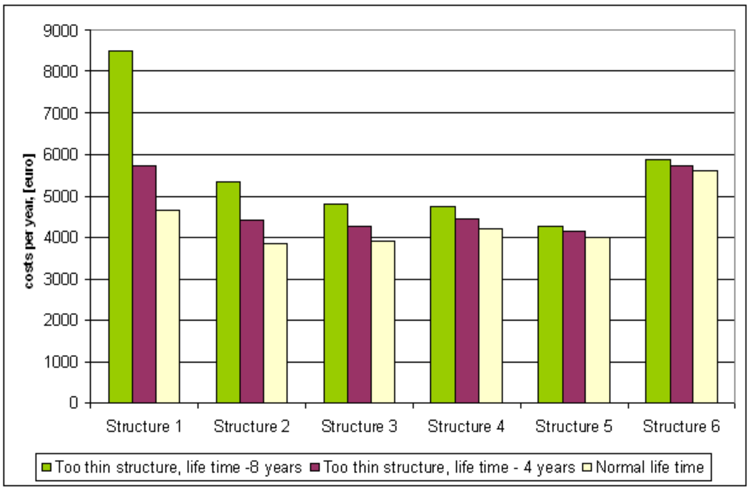

Figure 112. Structural options 1 – 6 and their lifetime costs per year. (Aho 2004)

According to the analysis results, the thinnest structural options (structures 1– 2) are more sensitive to variation of their lifetime (see figure 112). If the constructed structure is too weak compared with appearing spring thaw damages, the lifetime of the structure will be shorter (presented in figure 112 as –4 or –8 years). Thus the costs per year will increase rapidly. The shortening of the lifetime will not affect to the costs of thicker structures as much and that, as such, is why thicker structures (like 400 – 500 mm thick) should be favoured when repairing severe spring thaw damage.

In the analysis of repaired spring thaw problem sections that have failed, one factor that has repeatedly been observed as causing problems is that roads have been strengthened across the entire widened cross section. The reason for failures is that these widened shoulders hardly have any structures and differential frost heave and heavy vehicle driving on this firm looking shoulder will cause failures (figure 113.). Figure 114 presents a typical cross section that will fail and a cross section illustrating how strengthening should be done.

Figure 113. Failure on road shoulder. (photo: P Karhu)

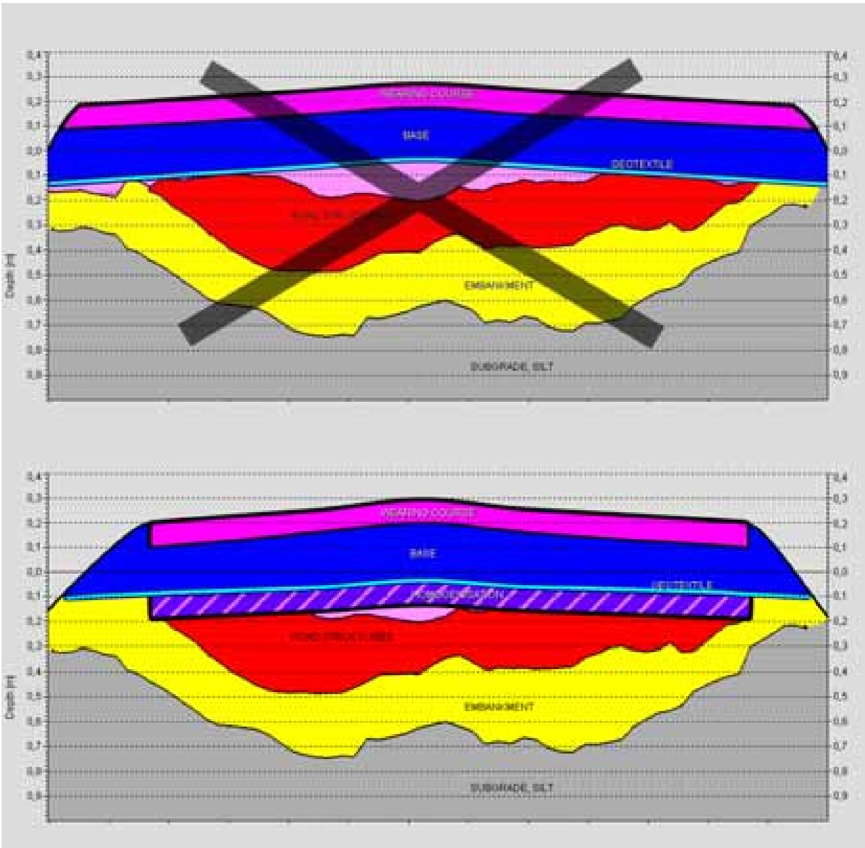

Figure 114. Typical cross-section that will fail and a cross section showing how strengthening should be done.

11.3.4 Homogenisation

If road owners have only very limited funding available, one of the cheapest techniques, which has been used to rehabilitate paved roads with spring thaw damage, is homogenisation + new surface dressing or new pavement. The homogenisation of the top part of the pavement structure using stabilization machinery and a new overlay works quite well as a light strengthening method for roads with damaged surface dressing or other cold mix pavement.

Figure 115. Homogenisation machinery made by Andament Oy from Finland. The same machinery can also be used for stabilization.

In the execution of this procedure the current surface dressing is first mixed with the base course (figure 115). The mixing depth is normally from 50 – 100 mm, or deeper, but it should not be so deep that it brings larger stones closer to the surface. After homogenisation the road surface is shaped to the optimum form, using a grader, and the homogenized material is compacted and a new surface dressing is made. In Finland, the price for this homogenisation process has been 0.6 – 1.0 €/m2 + cost for surface dressing or other pavement. This technique is especially good on roads with deep ruts, which are otherwise hard to treat. An additional benefit is that the road's cross section form will also be improved so that water will no longer lie on the pavement.

The solution of adding new base course material, which also makes the treated base thicker and improves the grading, has also been used on roads with major deformation problems during the spring thaw. In this technique the current pavement and the old base are first mixed and then the new base course is planed on the top and another run is made with the mixer prior to shaping, compaction and repaving of the structure.

Homogenisation has also been used in Finland on gravel road sections with spring thaw problems. In some cases, during the homogenisation process small amounts of slag sand have been added to improve the material quality.

11.3.5 Stabilization and treatment techniques

Stabilization and treatment techniques can be effective in strengthening the road against spring thaw weakening especially if a significant part of the permanent deformation occurs in the top part (0 – 250 mm) of the pavement structure. When done properly this stabilised structure will reduce the principal stress level in the unbound layer to a level where permanent deformation cannot develop. However differential frost heave can cause functional performance problems, such as wide cracking, for stabilized roads.

According to the latest results from stabilization tests, done with different treatment agents, on base course materials it is important to bear in mind that on low volume roads the problem is not mainly in the resilient properties of the road materials but in the permanent deformation properties due to frost susceptibility and water susceptibility. As such, the most important thing, when designing stabilization, is to ensure that the stabilized material is not adsorbing water if it is available. Results have shown, for instance, that extra bitumen content will result in higher deformation rates in the structure (Kolisoja and Vuorimies 2005).

More information about stabilization and treatment techniques is given in the Roadex II report “Material treatment” by Kolisoja and Vuorimies 2005.

11.3.6 Reinforcement

In this report, the term “reinforced structures” is used to refer to structures that are reinforced using a geotextile or a steel grid. In the Roadex II partnership area, geotextile reinforcement is only used in Scotland on low volume roads (see Roadex CD rom 2001). It can be used to prevent old structures from mixing with new structures, to improve bearing capacity, to reduce the damage caused by frost action and to strengthen road shoulders. Geotextile reinforcement can also withstand a certain amount of tensile stresses.

Conventionally, steel grids are used to prevent reflection cracking on paved roads. In the last few years there have been several projects, which have surveyed the functioning of steel grids in a road structure (REFLEX 2002). In these projects steel grids have also been tested in improving bearing capacity. During the last few years field experience has shown that steel grid structures could also be used to prevent permanent deformation in spring thaw damage sites. The benefits of steel reinforcement seem to be better the weaker the subgrade is. An example of a steel grid rehabilitation structure used to strengthen spring thaw damage sites is presented in figure 109 and table 11.

The first step in reinforcing a gravel road with steel grids is to remove the wearing course and homogenise the road structures as showed in figure 109. Before placing the steel grid the road should be shaped to proper cross slope using a grader and by adding about 50 mm (0-35mm, 0 – 55 mm) of coarse grained granular material and then finally compacted. Under the granular material it is also recommended that geotextile (filter cloth) be used to prevent old structures from mixing with the new structures. After placement of the steel grids the rest of base course is laid over top and then compacted (figure 116). The base course thickness is normally 200 – 400 mm depending on the severity of the spring thaw damage. When using steel grid structures either on paved or on gravel roads it’s important to install the steel grids deep enough (optimum depth is 250 mm from the surface) and to ensure that the road structure doesn’t contain any big boulders, which might push the steel grids up to the surface.

Figure 116. Base course is laid over steel grid. (photo: T. Ruohomäki)

In a test study, two structures containing steel grids were used for strengthening road against spring thaw damage in summer 2003 on road 9613 Vuojärvi - Tohmo in Kemijärvi, Finland. Structures containing steel grid were implemented in gravel road sections with very weak peat subgrade. Figure 117 presents GPR results after and FWD results before and after the structure was finished. It's quite apparent that the FWD deflections decreased significantly following construction of the steel grid structure. The maximum deflection values have decreased from 6000 μm to less than 2000 μm and especially the deflection values obtained further away from the loading plate decreased. This means that the hydraulic pressure under the truck load, which forces water upwards into the road structures, is markedly reduced.

Aho (2004) used these structures (figure 117) in her research in an attempt to determine which part of the decrease in deflections reduction is as a result of the steel grids and which part as a result of using an unbound base course. In doing the calculations, she used partly the same methods used in the REFLEX projects (2002). She estimated the effect of steel grid on permanent deformation of the subgrade by using the value of q/p and q/q_f as Dawson and Kolisoja (2005) did in the Roadex II report "Permanent Deformation". These calculations showed that the use of steel grid in a structure corresponds about 70 – 80 mm thick unbound base course layer against spring thaw weakening.

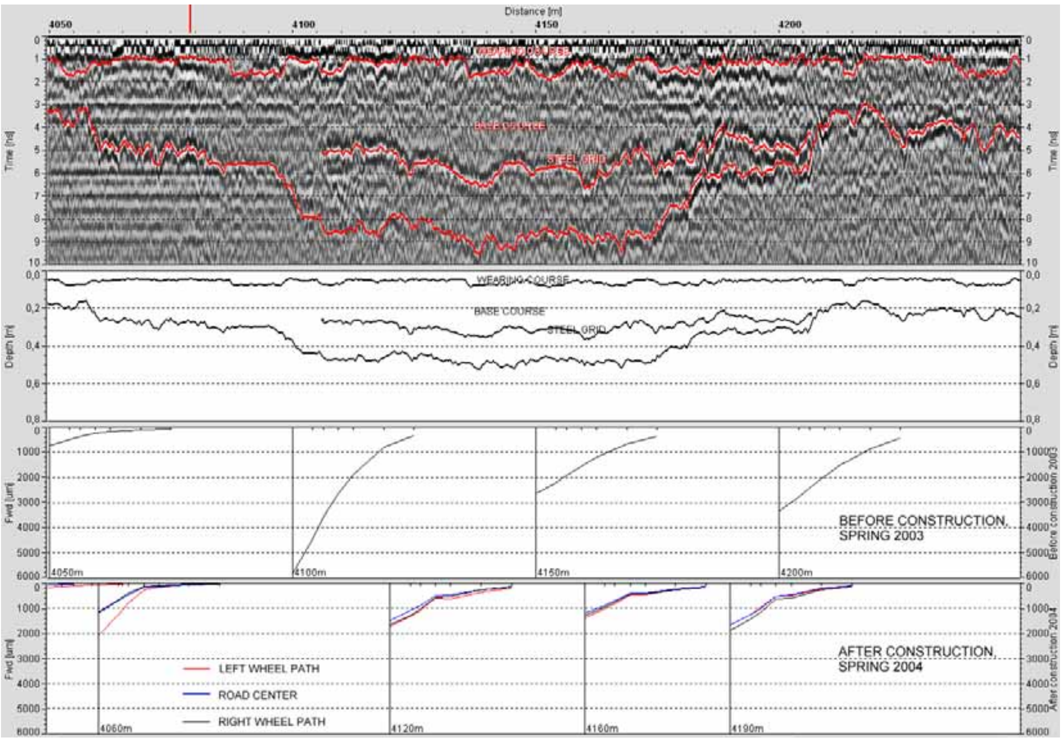

Figure 117. GPR data after and FWD results before and after construction of spring thaw damage strengthening structure on road 9613 in Kemijärvi, Finland.

12 Methods for spring thaw weakening management

12.1 General

Depending on the scale and scope of the spring thaw weakening problem there are several policies and techniques for managing a road during this weak period. In general the management tools can be divided into 1) different maintenance techniques to reduce the effect of spring thaw 2) using load restrictions and using different tools to minimize the problems caused by these restrictions, 3) strengthening weak road sections to the extent that load restrictions can be removed or used only in extreme conditions and 4) cooperation with transportation organizations using heavy vehicles. Most of these things are already being used in road regions in the Northern Periphery but new research results concerning road materials and their treatment techniques as well as new monitoring techniques used in combination with modern information systems can provide more efficient tools and applications to manage the problem. A greater focus on location, structures, timing and information systems will reduce the spring thaw problems or in the best case eliminate them.

12.2 Maintenance techniques

12.2.1 Drainage

Because frost heave and spring thaw weakening problems are always related to high moisture content in the road structures and subgrade soil, the cheapest and easiest way to minimize these problems is to ensure the optimum performance of the road's drainage system. A functioning drainage system prevents rainwater, ground water and thawing snow from infiltrating the road structures. Poor drainage of the road surface causes potholing on gravel roads as well as erosion on the road surface and ravelling and deformation in paved roads.

Ditches should be kept clean allowing the water flow freely. Statistical research done in Finland regarding the effect of drainage improvement in reducing spring thaw problems showed that the improvement of drainage ditches worked well for the first 2-3 years and then after that its effect slowly reduced until after 8 years it could not be seen in any statistical correlation (Ryynänen et al. 2003). This analysis results confirmed the general knowledge that ditches should be cleaned at 8-11 years intervals.

Culverts should be kept clean both in summer and winter. The Roadex II road users survey showed that uneven frost bumps, caused by culverts, often necessitated emergency breaking by heavy vehicles. This type of situation creates a definite a traffic safety risk and, as such, these sections should be repaired through the installation of frost heave transition wedges around the culvert.

Correct timing of maintenance action is also critical in reducing surface thaw weakening damage. Snow walls should be removed from the road shoulders before that surface thaw period begins so that melting snow will not keep the wearing course wet.

More information about drainage is given in the Roadex II Report 2005 "Drainage on Low Traffic Volume Roads" by Geir Berntsen and Timo Saarenketo.

12.2.2 Gravel road maintenance

There are also several techniques that have worked well in reducing the effect of spring thaw weakening on gravel roads. During the grading of the wearing course in the fall the cross slope should be as close to 5 % as possible. This ensures that the wearing course will be as dry as possible when it freezes and thus surface thaw softening problems can be reduced.

Another maintenance technique used to prevent surface thaw weakening on gravel roads especially is to make certain that gravel road wearing course does not become too thick. Road surveys in Finland have shown that a wearing course that is thicker than > 150 mm and that has a high fines content, greater than 16 %, will cause spring thaw weakening problems in a moist environment. The top part of the wearing course in such road sections should be removed or another option to mix course material into the wearing course. One way of maintaining gravel road wearing course is measuring its thickness and moisture content using the surface GPR reflection method as described in figure 118.

The excessive use of dust binding chlorides, during gravel road routine maintenance, can cause severe surface thaw weakening problems because they increase osmotic suction, which can cause the wearing course to adsorb an excessive amount of water. Chloride content in the wearing course of higher than 2000 mg/kg has proven to cause plasticity during the spring thaw period (Saarenketo & Vesa 2000). In general, dust binding additives should not be used on moist sections with known spring thaw problems because, in a wet section, there are no dusting problems and if chlorides are used they will be transferred into the ground water quickly through capillary zones.

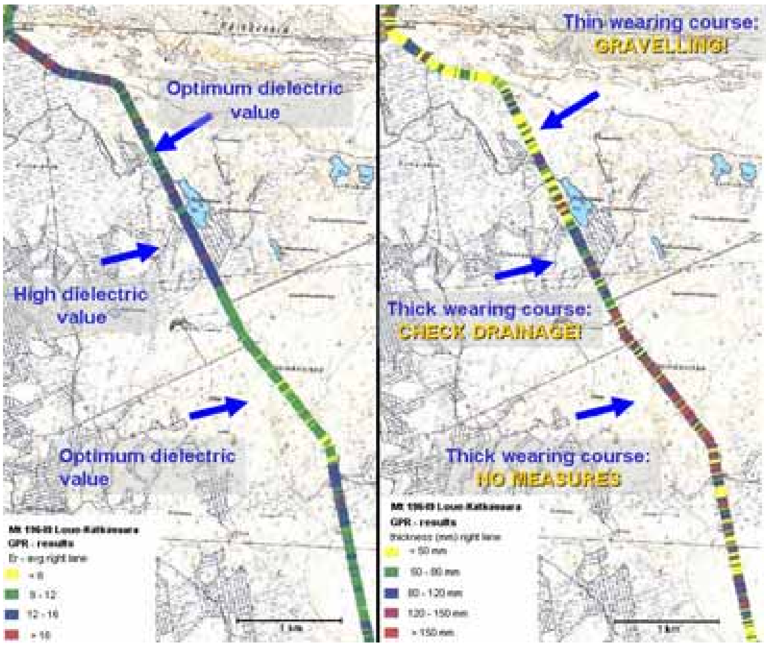

Figure 118. Example of the evaluation of the need for maintenance on a gravel road wearing course based on the wearing course thickness and dielectric value measured using GPR techniques (see Saarenketo and Vesa 2000).

12.2.3 Maintenance of paved roads

Maintenance of paved roads directed toward preventing spring thaw problems is mainly related to ensuring a working drainage system. The Roadex II drainage project (Berntsen and Saarenketo 2005) showed through theoretical calculations and field testing that by keeping the drainage in good condition it is possible to increase the pavement lifetime 1.5 – 2.5 times compared to the lifetime of a road with poor drainage conditions. In addition to that, it should also be ensured that pavement cracks are sealed and that water cannot infiltrate the pavement.

12.3 Spring thaw monitoring techniques

12.3.1 Visual inspection

The visual inspection technique, used in Finland routinely since 1996, has proved to be a valuable method for monitoring the scope and scale of spring thaw weakening problems on gravel roads. Currently, Finnra has excellent data bases where information can be collected and analysed to evaluate how severe spring thaw weakening is in each year as well as evaluating the trend of the spring thaw weakening in each year. Spring thaw weakening data has also proven to be excellent basic information for use when designing rehabilitation measures for gravel road sections.

After 1998, when the trained crews, instead of local maintenance personnel, started doing the monitoring the quality of the results improved. Instead of using trip meters damage is positioned with GPS, which has proven to be more accurate. The problem with this method is that it is still based on visual evaluation and thus is subjective. The timing of these surveys is very important in order to obtain reliable data.

12.3.2 Monitoring cameras

Spring thaw weakening can also be monitored through camera systems, similar to those used for weather or traffic monitoring. Although the authors do not have any knowledge of such systems being used for this purpose, cameras on mobile phone platforms present some interesting possibilities for monitoring road condition. A mobile phone based camera could be installed at a site, known to have spring thaw problems, from which it could transmit photographs on a daily basis. The photographs could, in turn, be used to monitor the condition of the road and the need for weight restrictions.

During the Roadex II tests in Kuorevesi, Ängesby and Kemijärvi a photo was taken of each site once a day throughout the spring thaw season. These series of photographs provided a good chronological view of how the spring thaw progressed. Photographs would be especially useful during and after surface weakening and after heavy rainfalls to evaluate if the weakening has become critical and gravel road surface has become plastic.

However on paved roads there is not much advantage to using cameras because when visual distress begins to appear in the pavement surface it is already too late to do anything.

12.3.3 Temperature sensors and other sensors

In many countries temperature sensors have been used to monitor the frost depth during the thawing period. In Sweden, the Road Administration has built a network of temperature sensors around the country where it is possible to monitor, in real time through the SNRA web site: http://www3.vv.se/tjaldjup/, the temperature below the road surface. Figure 119 presents an example of information that can be seen from the web site. The Krockbana results from March 2005 provides valuable information about how frost thawing.

Figure 120 gives an example of data provided by a temperature sensor system made by Finmeas Oy and installed in the road in Vihti in Southern Finland. The greatest advantage of these temperature sensor systems is their low prices compared with other monitoring techniques that use sensors measuring various parameters about spring thaw weakening. The advantage of a temperature sensor system is that they can be spaced only a few centimetres apart and they use a flexible cable that can withstand the stresses caused by frost heave.

Figure 121 presents the results from frost depth measurements in Olmstead County from winter 2004-2005 (http://www.mrr.dot.state.mn.us/research/seasonal_load_limits/sllindex.asp).

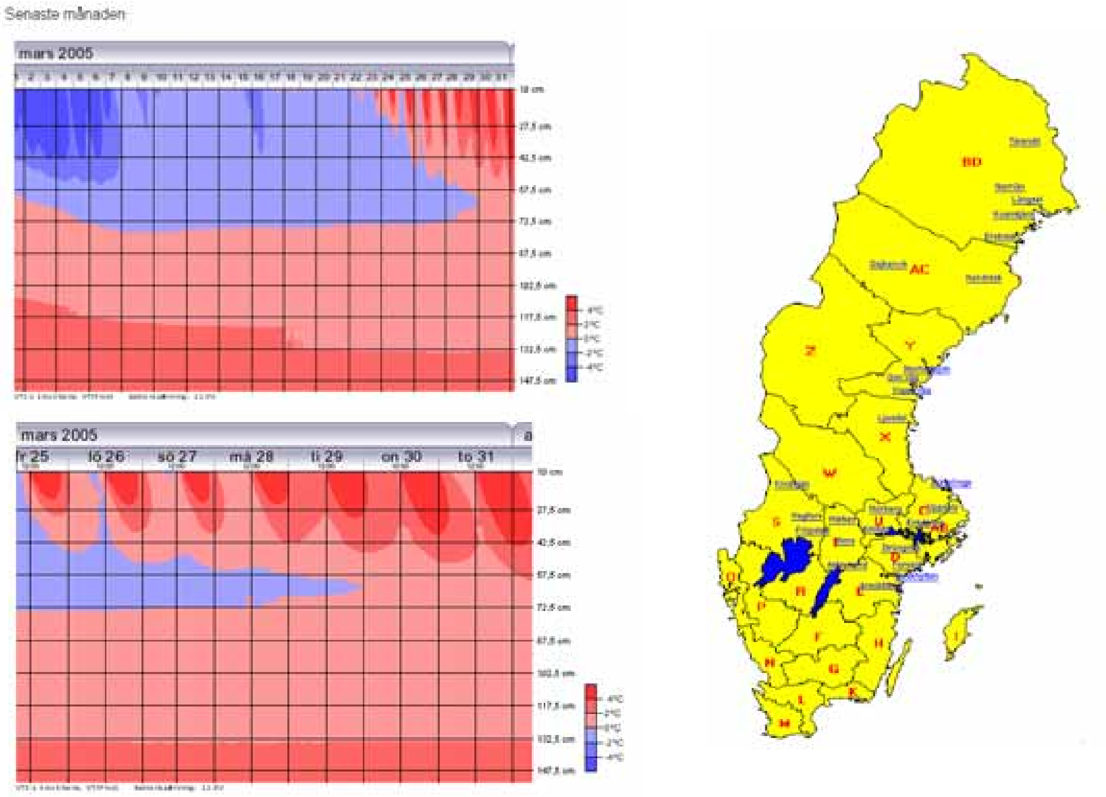

Figure 119. Location of Swedish frost sensor network (left) and an example of the survey data displayed at the www-site for the Krockbana monitoring site (right) during the spring thaw period in 2005. The upper graph presents the results from March 2005 and the lower profile presents a detailed reading from the last week of March 2005 (Swedish Road Administration 2005).

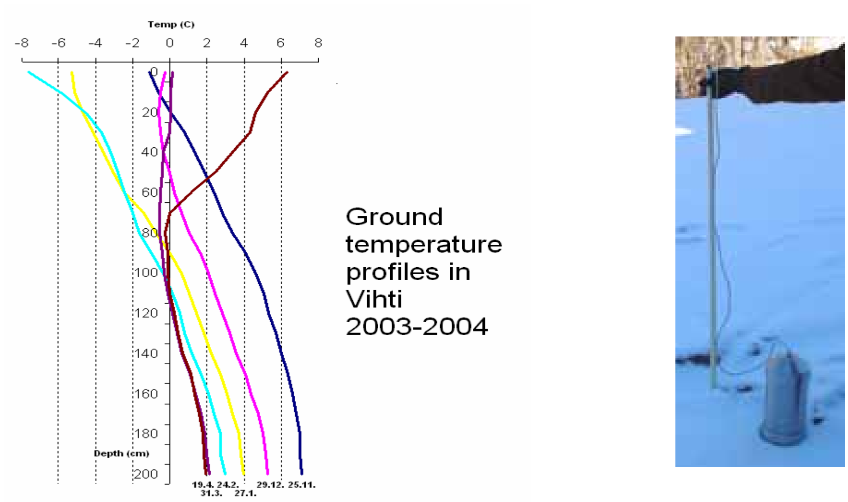

Figure 120. Finmeas temperature sensor system used in Southern Finland and an example of a data display from the Vihti survey station in 2003 – 2004 (Finmeas Oy, Finland).

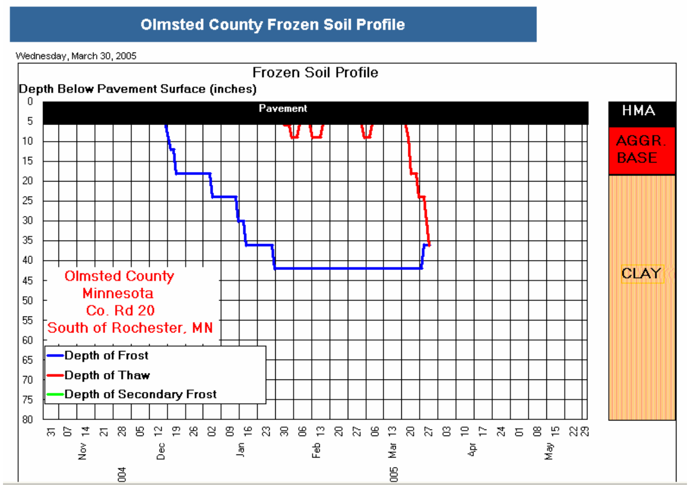

Figure 121. Frost depth profile from an Olmstead County monitoring Station in Minnesota. (Source: http://www.mrr.dot.state.mn.us/research/seasonal_load_limits/sllindex.asp).

12.3.4 Dielectric value and electrical conductivity

The problem with the temperature sensors is that they can only determine if the temperature in the material is below 0°C and, as such, the sensors are only useful during the springtime to monitor when the material has completely thawed i.e. it no longer has any frozen ice. Because the freezing point varies with different materials, dielectric value and especially electrical conductivity should be used to monitor the elapsed time for a material to freeze and the date when a material has completely frozen in the winter. This information can then be used to make models for predicting the severity of the spring thaw

During the spring thaw the most critical parameter is volumetric moisture content which can be determined by measuring dielectric value of the material. Changes in moisture content have traditionally been monitored using the TDR technique (O´Connor and Dowding 1999, see Berntsen and Saarenketo 2005) and by capacitance based Percostation method used in this Roadex survey.

Electrical conductivity is a good indicator if the material is completely frozen. During the thawing periods it can also reveal the degree at which clay colloids are being released into the pore water and how susceptible the material is to plastic deformation. Electrical conductivity shows well the surface thaw period during the spring and can be used to detect if ground water containing clay colloids is being squeezed up to the road surface due to heavy traffic loads. Electrical conductivity, or resistivity, can be measured using the Percostation technique. This parameter has been used traditionally to monitor ground freezing especially in permafrost areas.

12.3.5 Ground water level

The ground water level around the road, especially during the freezing season in autumn and early winter, has an influence on how severe the coming spring thaw period will be. Ground water level sensors can be used to make predictions for the coming spring thaw weakening. One such sensor station has been installed in the Uusimaa road region of Finland. This system, manufactured by Finmeas Oy, is installed below the ground water table and measures the ground water thickness above the sensor. When the depth of sensor is known then the depth of ground water table can be calculated. Figure 122 presents an example of the data.

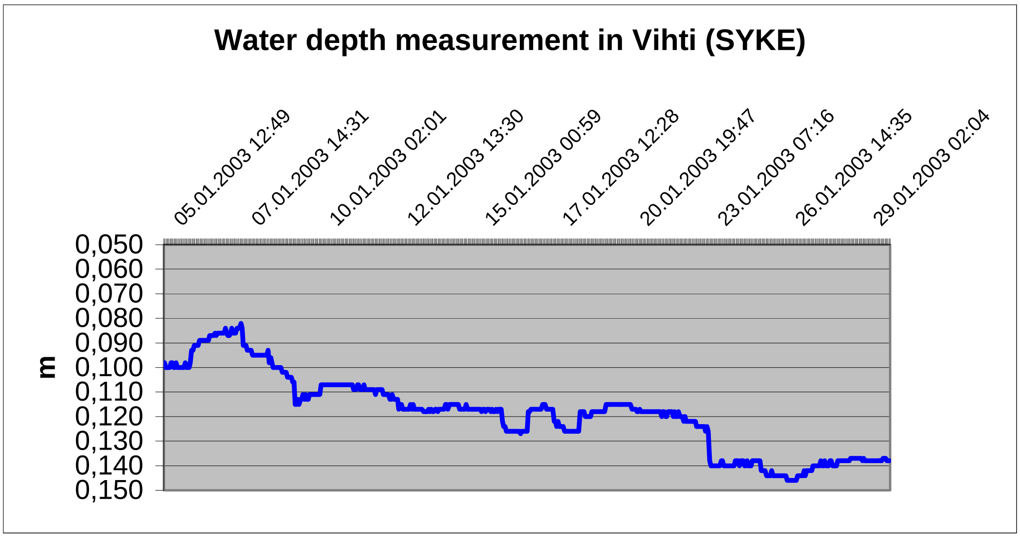

Figure 122. Ground water depth monitoring results from January 2003 from the SYKE survey station in Vihti, Southern Finland (Finmeas Oy).

12.3.6 DCP tests

The Roadex II project tests have shown that the DCP technique can be very useful for monitoring the thawing frost depth and especially the stiffness of the road structures above a weak subgrade. The DCP system is easy and cheap to build and simple to use in the field. In theory, a modified DCP system could be a standard tool for maintenance crews working on the road network. The results of a DCP test could then be transferred to a spring thaw management center where could be processed and used to make decisions whether load restrictions should be applied or removed.

The problem with the DCP technique, however, is that it has difficulties with penetrating if the base course is made of coarse grained granular material and, as such, it is not especially suitable for monitoring “well built” roads.

12.3.7 Portable FWD´s

Even though standard FWD systems provide very useful information about bearing capacity during the spring thaw period, this technique is too expensive for routine monitoring of the road structures during the spring thaw. But recently several portable FWD units have been introduced to the market and these could be used to monitor spring thaw weakening especially on weak gravel roads. However the load level is basically not high enough to obtain reliable data concerning the changes in bearing capacity on paved roads.

12.4 Monitoring loads

A key problem for future bearing capacity policies is how road authorities can monitor the axle weights and total weights used in the road network. Within the Roadex II partners countries Sweden has recently begun using a new and promising weigh in motion (WIM) technique (*VVPubl 2003:5)*, where sensors are instrumented onto the bottom of a bridge (figure 123). New WIM systems can give real time information regarding axle loads and total loads to which the road authorities can react if the load levels are too high.

Figure 123. SiWIM sensors instrumented onto the bottom of a bridge. (Photo from VVPubl 2003:5)

Figure 124, from a Swedish report (*VVPubl 2003:5)*, provides information concerning the percentage of overloads measured at SiWIM test sites in Sweden. The percentage of gross weight overload vehicles varies normally from 5 to 15 % while the relative percentage of overloads measured from single axle weights is slightly higher.

However when analysing the heaviest vehicles, with gross weight more than 35 tons, the results are more significant. Figure 125 shows that an average number of 20 – 30 % of these vehicles have gross weight overloads and the case is even worse with single axle overloads where in many places 30 – 50 % of the vehicles had overloads.

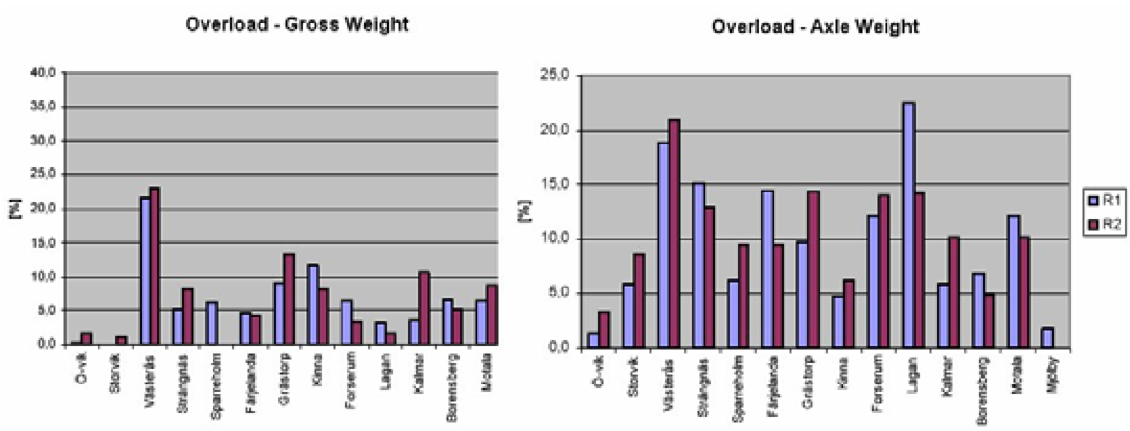

Figure 124. The percentage of gross weight overload and axle weight (> 13 ton) overloads from all the heavy vehicles passing the SiWIM test places in Sweden. Figure is from report VVPubl 2003:5.

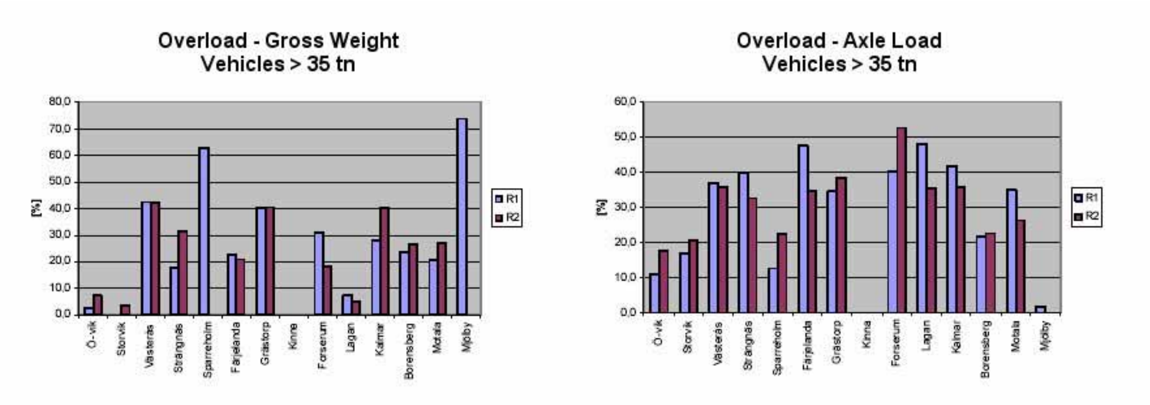

Figure 125. The percentage of gross weight overload and axle weight (< 13 ton) overloads from the heavy vehicles with gross weight more than 35 tons passing the SiWIM test places in Sweden. Figure copied from report VVPubl 2003:5

This WIM method provides an excellent tool for monitoring total weight and single axle weights during the thawing period. Road officials can monitor the total weights (see figure 126) or single axle weights at these stations on a daily basis and if the results show overloads actions can be taken.

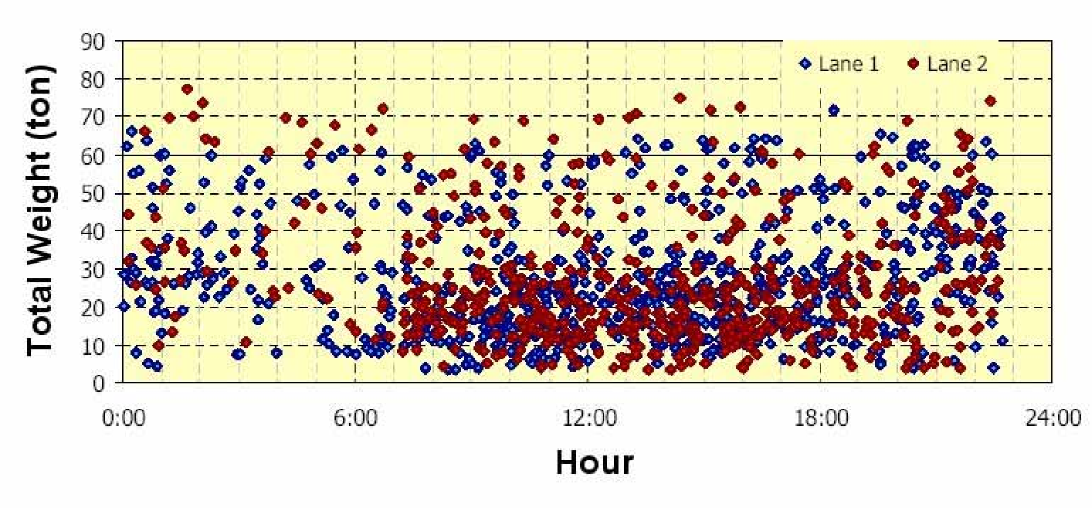

Figure 126. Total weight of heavy vehicles at the Strängnäs SiWIM station in the Mälardalen area in Sweden over a one day period. Figure is from report VVPubl 2003:5

A good review of other WIM techniques that can be used to monitor axle weights and total weights is given by Conway and Walton (2005).

In the future, instead of the WIM technique another way to monitor truck weights is through the use of air-spring suspension weight sensors installed on trucks and then inform the road owners of the loads using wireless communication techniques. More information regarding these techniques is given in chapter 12.7 of this report as well as in the Roadex report: Monitoring, Communication and Information Systems & Tools for Focusing Actions by Saarenketo (2005).

12.5 Controlling tyre pressure

One solution that has not yet been widely tested or used in the management of the timber transportation problems during the spring thaw period is to control the tyre pressure. Using the CTI (Central Tyre Inflation) technique it is possible for the driver to adjust the pressure of the truck tyres whilst the vehicle is underway (figure 127) and thus reduce the contact pressure that the tyres are placing on the road surface, road structures and subgrade soil (Granlund et al. 1999, Kestler et al. 2005). Trucks equipped with the CTI system can thus drive, fully loaded, on roads with load restrictions. Figure 128 which has been modified from Granlund et al. 1999, presents the benefits of the CTI system compared to a truck without CTI. Using a greatly reduced tyre pressure widens the contact area by almost 60 % compared with the normal air pressure.

In CTI tests conducted in Sweden during the winter of 1997-98, road authorities granted a dispensation to one truck equipped with CTI to carry full payloads on the road. The haulier did not have to make multiple trips with reduced loads and also avoided time consuming reloading. In one project, a standard truck would have had to make 260 trips to transport all the timber but the CTI equipped truck required only 95 trips. Moreover, the road did not appear to have been damaged by the truck. The savings in transportation costs are time and labour costs as well as fuel costs. In the Swedish tests the savings in the different haulage projects varied from 2 to 6 €/ton (Granlund et al. 1999).

Figure 127. CTI system installed on a dual tandem wheel (photo courtesy of Curtis Berthelot)

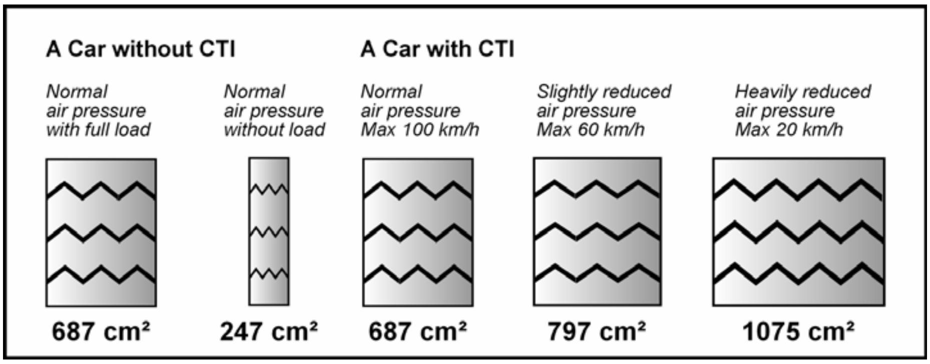

Figure 128. The contact area of the trucks, using different loads, with and without the CTI system. Figure modified from the Granlund et al. 1999.

According to Granlund et al., in 1999, the additional cost of equipping a truck with the CTI system is roughly 7.000 – 8.000 euros. However, even if these systems are approved for use during the spring thaw weakening period, road authorities will still need to grant special permission for these trucks to drive those roads with load restrictions. Other vehicles where these systems could be, or should be, used include those heavy vehicles, such as dairy trucks, that need to drive these roads daily. The start up cost for the CTI system is minor compared with the cost of damage that a single truck can cause on a weak road during the spring thaw period. In Canada cost estimates made in the Rural Partnership Haul Program have shown that CTI integrated with a real time spring thaw monitoring system and a vehicle control system can even reduce, by up to 50 %, the haulage costs of big road trains with high total loads (Lang et al.2001).

However some problems have also been reported regarding the use of CTI techniques. The use of insufficient tyre pressure has a risk causing the side walls of the tyres to feather which could lead to a tyre failure in as few as two kilometres if the tyre is too soft. Sidewall failures are especially a risk on forest roads (Scottish Enterprise 2003). According to Kestler (2005), the CTI technique does not prevent all the damage done to paved roads but reduces them markedly. She proposes that the load restriction window can be shortened on paved roads through the use of low tyre pressure. The trucks could use the road for an approximately two to four week period prior to the anticipated end of the standard load restriction period (Kestler 2005).

Figure 129. Forestry sector partnership experimental Twelve-Axle B-Train used in Saskatchewan Rural Partnership Haul Program (photo Curtis Berthelot)

12.6 Special axle configuration systems

The Forest Enterprise in Scotland has been developing another solution to the problem of permanent deformation caused by repeated high loads on the wheel paths of low volume roads (Scottish Enterprise 2003). In these tests, instead of lowering loads or tyre pressures, a test truck with a special axle configuration has been used to haul timber from forest roads (see figures 130 and 131). In these "Low Ground Pressure" trucks, the tyres are placed on different parts of the truck axles in order to minimize the repeated load cycles on a road structure. These axles and wheels are designed to reduce ground pressure overall and spread much of the weight in the middle of the road, where the road is strongest. This configuration evenly rolls and evens the road surface, and reduces the rutting, commonly seen in Scotland, when super single are used for timber haulage.

Figure 130. Low ground pressure vehicle.

Visual evaluation of the road surface after the tests in Galloway Scotland confirmed that the low ground pressure vehicles are generally less damaging than conventional trucks and that these vehicles had a beneficial effect on road surface. The only problem has been scrubbing when multi-axle trailers are pulled round corners and wheels are dragged transversely across the road causing scraping of the surface layer. This problem was reduced by a special double articulation system (Scottish Enterprise 2003.

One idea was to develop specialized vehicles that are both robust and less damaging to forest roads to deliver timber to skeletal trailers parked on landings near public roads (Scottish Enterprise 2003).

Figure 131. Axle configuration of a Low Ground Pressure Vehicle spreads much of the vehicle load onto the road centre.

12.7 Optimising weight restriction timing and truck loads

As reported earlier it can be generally stated that during the spring thaw weakening period every single day causes extra cost for the forest industry in Sweden and Finland more than 1 million euro. That is why all kinds of optimisation systems that can be used to shorten the length of load restrictions are that allow increase of loads step-by-step without damaging the road network are welcome and profitable for society. That being the case there is still a need to improve the previously mentioned real time spring thaw monitoring technology and at the same time create a quick decision making system along with a well functioning notification system for the road users.

In Finland, the Finnish Road enterprise has tested a method where all of the maintenance truck drivers in a certain area are trained to monitor visually and make reports regarding the status of spring thaw weakening. This information is gathered together and then both a short term and a long term forecast are made for the forest industry and haulage companies. The feedback from this system has been positive but the problems have been the cost of the system and a limited number of customers willing to pay for the service (Litmanen 2005). However this kind of system could still be considered in the optimisation of load restriction timing but it requires the establishment of a partnership between road administrations, maintenance contractors and haulage companies.

Modern information technology offers several options for transferring information regarding known spring thaw problems and roads with load restrictions. Using frost depth and moisture content monitoring systems it is possible to monitor, in real time, the thawing of the frost through temperature as well using dielectric values as indicators of moisture level and electrical conductivity values to indicate the risk of plastic deformation. As presented earlier in this report (see chapter 7.1) this information could be sent to spring thaw monitoring centres for further analysis and a well informed decision to either impose or lift weight restrictions could then be made. In an ideal system this information would require, at least during the first years, supporting information regarding the stiffness of road structures from either DCP or FWD measurements.

Based on the real time results from these monitoring systems, it will be possible, in the future, to increase axle loads step-by-step and, in addition, to monitor and ensure that haulage companies are not violating these restrictions. Figure 132 presents an ideal spring thaw management system that could be established in cooperation with road owners and haulage companies. In this system, a Spring Thaw Management center collects real time information from the spring thaw monitoring stations and results from field crews conducting DCP tests and then determine if weight restrictions are needed or not. The center could also calculate, if trucks were using CTI and air spring suspension weight sensor systems, what the greatest allowed maximum weight would be and if CTI has to be used on these critical road sections. This information would then be sent to the trucks' computers through GPRS systems thus providing direct notification of maximum weights and CTI requirements for route planning purposes. Then after loading the trucks to the allowed weight, trucks would send a message to the spring thaw management centre through an automatic vehicle identification (AVI) system (see Saarenketo 2005) which can also be used to verify the truck weight, the route they use and if they are using CTI on the critical road sections.

The proposed technology and cooperation, which is a modification of the technology idea proposed and developed for use in Saskatchewan (see Lang et al. 2001, Conway and Walton 2005), would require certain investment costs for both the road administrations and haulage companies, but in the long term, would generate major savings for both parties and the results would be also seen in a reduced rate of deterioration in the low volume road.

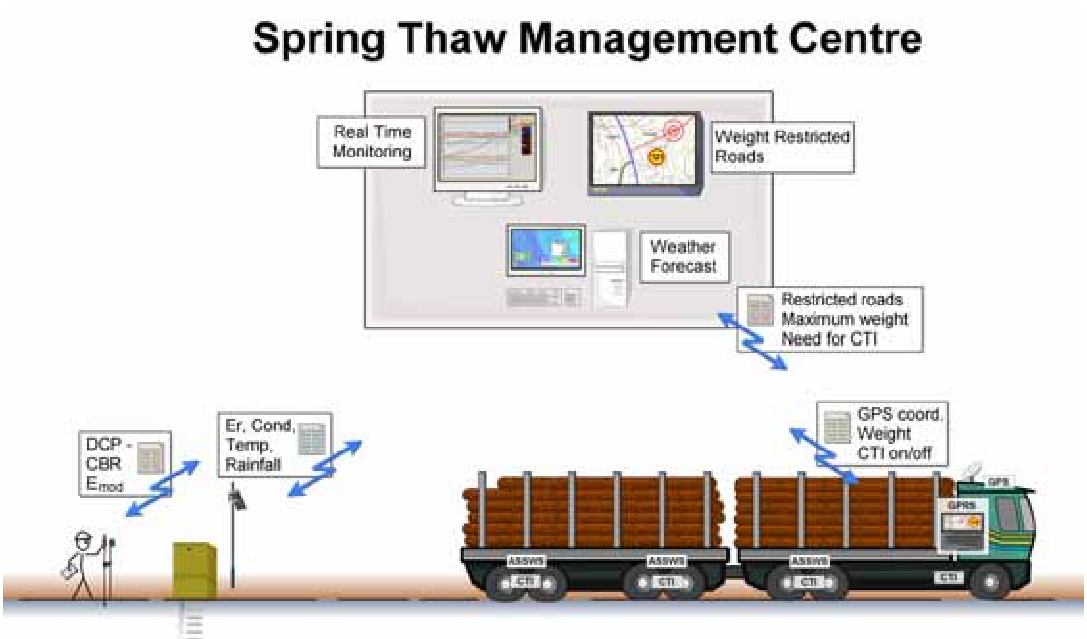

Figure 132. A description of a spring thaw weakening management system for optimizing load restriction timing and maximum allowed total weights as well as controlling heavy vehicle operations on the problem roads through the Spring Thaw Management Centre.

12.8 Information systems

A key element in successful management of spring thaw weakening is how to inform road users of the load restrictions and about weak and dangerous roads. The forest industry and haulage companies, especially, require reliable information early enough to be able to make a harvesting and transportation plan that will ensure the raw material supply. They also need real time information concerning the status of thaw weakening and load restrictions. Currently, information obtained via web pages is becoming a more and more important media in this task. Figures 133 and 134 present examples of Finnish and Swedish road administration web page information regarding the load restrictions. In the future this information will most likely be sent directly to the truckers´ computers and navigation systems through wireless networks. More text concerning the information and communication systems is published in the Roadex phase III report “Monitoring, Communication and Information Systems & Tools for Focusing Actions” by Saarenketo (2005).

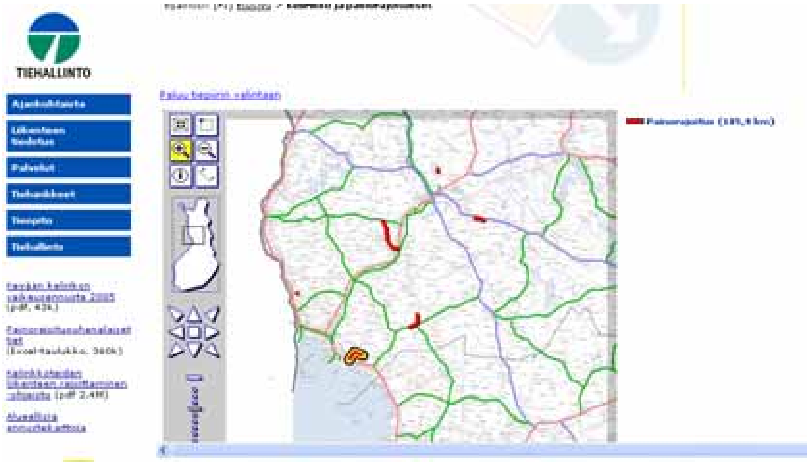

Figure 133. A map showing roads with load restrictions is presented on the Finnra www pages: http://www.tiepiiri.com/palvelu/liikennetiedotus/kelirikko/

Figure 134. The www pages of the Swedish Road Administration present both load restricted roads and also road sections with difficult differential frost heave problems.

12.9 Transportation planning

The results presented earlier in this report state clearly that the best option for ensuring proper road condition over the long term is to avoid using the road during the weakest period in spring. Since most of the timber is first transported over weak forest roads, that are not passable during the thaw period, there will always be a need to make special arrangements for timber haulage in order to assure a continuous supply of raw material for the forest industry. The extra costs incurred by these measures can be minimized through good transportation planning which also requires a high level of cooperation between the forest industry, haulage companies and road administrations.

The most popular method has been to haul timber from road networks in areas suffering from spring thaw problems to temporary stockpiles in the vicinity of better roads with no load restrictions. An example of just such an arrangement in Region Norr, Sweden can be seen in the photo on cover page of this report. If the roads are very weak, this can be an economical solution and in Finland some road regions have built these timber storage areas for the forest industry.

Figure 135 shows an example of another transportation option from the Rovaniemi railway station. In this area, timber is hauled during the winter months from throughout Finnish Lapland and then stored in a large stockpile area at the Rovaniemi railway station. Timber from this stockpile area is then loaded onto trains during the spring thaw period and transported to the timber industry facilities. This system saves the additional costs incurred by loading and unloading the timber trucks more than once.

Figure 135. Timber stockpiles at the Rovaniemi railway station during the load restriction period in May 2004 (left) and then late summer in August 2004 (right).

However, the stockpiling of timber also causes problems with regard to the quality of certain raw materials. Especially ground wood, made from spruce, has to be fresh because the wood fibres are ground mechanically using a rock. If the spruce is dry, the amount fibres will be lower and they will be of lower quality. More chemicals are also required to whiten paper made from dry wood (Marjakangas 2005).

According to Marjakangas (2005), that is the reason why Stora-Enso has started to use a new stockpiling technique where fresh yet still frozen timber is stockpiled close to the pulp mill where it is kept frozen by covering the stockpile with a 50 – 100 cm thick layer of artificial snow which is then covered with a 30 cm thick layer of sawdust. In spring 2005, Stora-Enso has stored 27300 m^3 of fresh spruce at their Veitsiluoto pulp mill in Kemi (figure 136). This storage will be opened at the end of August and it is used together with new fresh timber until end of September. In Southern Finland this techniques has been used for several years and for saw logs as well.

Another factor governing timber harvesting, stockpiling and transportation planning in Finland is the act on the insect and fungoid damage (8.2.1991/263) which regulates that pine can only be harvested between September and May and must be hauled away from stockpiles by August 15th in Lapland and by July 15th in the Oulu area. In Southern Finland this period is even earlier.

Figure 135. Stockpiling frozen timber at the Stora Enso Veitsiluoto factory in spring 2005. Photos: Kari Marjakangas.

13 Summary and discussion

This Roadex report was written in six major parts. The first part of the report presents the theory behind spring thaw weakening; the scope and the scale of the spring thaw problems as well as the different load restriction policies used in the cold climate areas. When looking at the policies in the NP area and the use of load restrictions it is not clear if the total socio-economic costs are beneficial. Load restrictions are saving the road but there is not enough information concerning the effect that these traffic restrictions have on rural development. If they are used in the future it will not improve regional parity, for instance the forest industry already pays better prices to landowners for timber that is located close to a good quality road. In the future, in the investment plans of the forest industry and other industries that have their raw material supply in rural areas, the requirement of ensuring that logistical chains remain open will have ever increasing role. As such, the only goal for all public road administration should be the complete removal of load restrictions. This cannot be done at once but with a long term policy it is achievable.

The second part of the report summarizes the key results of the extensive field testing done at the Roadex test sites. In Scotland, by monitoring the dielectric value, electrical conductivity and temperature of unbound base as well as daily rainfall it was possible to monitor critical times when the road was at a high risk for failure under heavy traffic. This occurred especially after freeze-thaw cycles. In Scandinavia, even though the springs of 2003 and 2004 were quite “easy” in terms of spring thaw weakening, the Roadex II project monitoring results from each test site showed the similar weakening phases during the spring thaw period. In terms of traditional bearing capacity, measured using FWD, the road was weakest after the frost had completely thawed. This was in contradiction with the fact that load restrictions have always been removed in both Finland and Sweden before the frost had completely thawed. But if road authorities had waited until the period of highest deflections was over, as it is done in North America, there would still have been load restrictions in mid or even late July in Northern Scandinavia. So more important than the actual deflection values, or measuring thawing index, is to focus on the stiffness of the upper road structures and their ability to carry loads and how long a recovery time the road needs after each truck passes. A weak low volume road is like a relatively stiff mattress floating, on a layer of water created by melting ice, and at the same time settling. The risk for failure then depends on how dry and stiff the road remains thanks to weather conditions and how much time the road has to recover from an intrusion of water into the structures caused by a passing truck.

The third part of this report presents a new classification for spring thaw weakening phases that can be used in monitoring and communication terminology when describing the status of spring thaw but is should be used also in decision making process for the need of load restrictions or removing them. Figure 136 summarizes these phases and presents a process of how to evaluate the need to impose or remove load restrictions on gravel roads.

In the fourth part a new classification for spring thaw weakening sites is presented. This classification is important in order to be able to select an optimum strengthening method for each type of spring thaw problem. These strengthening techniques and structures and their life cycle costs are presented in the fifth part of this work. The results clearly show that each spring thaw weakening problem section requires good survey data, correct diagnosis and careful design in order to produce sustainable repair solutions.

The sixth part of this Roadex II report presents methods, both old and new, that could or should be used in modern spring thaw weakening management on low volume roads in the Northern Periphery. The report presents both maintenance and monitoring techniques but reveal also new promising technologies that heavy trucks can use to reduce the stresses to the road structures during the spring thaw period.

The Roadex II survey results regarding seasonal changes and spring thaw weakening produced valuable information regarding the processes behind road damage and the complexity of these processes. Test results indicated that standard truckloads can easily break the road during the weakest phases in spring incurring major costs to road owners as well as an unpleasant ride for other road users during the rest of the year. On the other hand it can be estimated that in Finland and in Sweden, for instance, every day of load restrictions results in more than one million euro extra cost for the forest industry. The results also reveal that the critical weakening phase is often quite short and that is why good monitoring systems with better spring thaw weakening models will allow major savings for the haulage companies using low volume roads. Based on real time results from these monitoring systems it will be possible, in the future, to increase axle loads step-by-step and, in addition, monitor and ensure that haulage companies are not violating these restrictions. Other promising solutions that haulage companies could use and that should be studied further are the idea of recovery times after a truck pass and the use of CTI (central tyre inflation) techniques or special axle configurations to reduce the risk of damaging roads during the spring thaw. Current technology allows trucks to report to road owners, in real time, their total weights and whether or not CTI is being used on the restricted sections, which would further increase the trust that the trucks are observing the restrictions. However as stated earlier the long term goal should be to repair and strengthen all the weak road sections, and only the weak sections, so that load restrictions would no longer be needed.

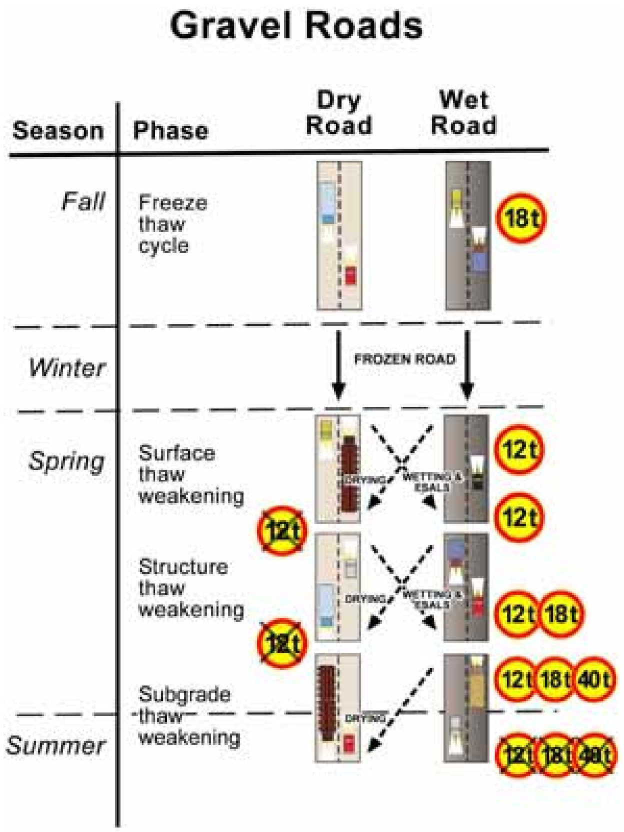

Figure 136. A schematic figure detailing the process for optimization of the load.

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Appendix 1 – FWD RESULTS KEMIJÄRVI

Table 1-1: Back calculated moduli values at four load levels measured at Kemijärvi test site 24.4.2003.

24.4.2003	**LINE 3.**	**LEFT LANE OUTER WHEEL PATH**				
Road Structure	Layer	Thickness (mm)	Modulus 12.5 kN	Modulus 27.5 kN	Modulus 40 kN	Modulus 50 kN
Wearing Course + Base	1	150	300	350	400	450
Base	2	150	60	60	60	60
Embankment	3	100	30	30	30	30
Silt 1.	4					
Silt 2.	5					
Frozen ground	6		500	800	700	850

24.4.2003	**LINE 2.**	**ROAD CENTER**				
Road Structure	Layer	Thickness (mm)	Modulus 12.5 kN	Modulus 27.5 kN	Modulus 40 kN	Modulus 50 kN
Wearing Course + Base	1	151	350	400	450	500
Base	2	150	50	50	50	50
Embankment	3	99	40	40	40	40
Silt 1.	4					
Silt 2.	5					
Frozen ground	6		600	1000	1100	1200

24.4.2003	**LINE 1.**	**RIGHT LANE OUTER WHEEL PATH**				
Road Structure	Layer	Thickness (mm)	Modulus 12.5 kN	Modulus 27.5 kN	Modulus 40 kN	Modulus 50 kN
Wearing Course + Base	1	160	250	300	320	350
Base	2	150	40	40	40	50
Embankment	3	90	40	40	40	40
Silt 1.	4					
Silt 2.	5					
Frozen ground	6		700	1000	1000	1000

Table 1-2: Back calculated moduli values at four load levels measured at Kemijärvi test site 6.6.2003.

6.6.2003	**LINE 3.**	**LEFT LANE OUTER WHEEL PATH**				
Road Structure	Layer	Thickness (mm)	Modulus 12.5 kN	Modulus 27.5 kN	Modulus 40 kN	Modulus 50 kN
Wearing Course + Base	1	150	140	170	180	190
Base	2	150	50	50	40	40
Embankment	3	300	20	15	15	15
Silt 1.	4	100	10	10	10	10
Silt 2.	5	100	10	10	10	10
Frozen ground	6		300	400	400	300

6.6.2003	**LINE 2.**	**ROAD CENTER**				
Road Structure	Layer	Thickness (mm)	Modulus 12.5 kN	Modulus 27.5 kN	Modulus 40 kN	Modulus 50 kN
Wearing Course + Base	1	151	200	250	250	300
Base	2	150	50	50	50	60
Embankment	3	239	10	10	10	10
Silt 1.	4	170	7	7	5	5
Silt 2.	5	90	5	5	5	5
Frozen ground	6		800	900	900	900

6.6.2003	**LINE 1.**	**RIGHT LANE OUTER WHEEL PATH**				
Road Structure	Layer	Thickness (mm)	Modulus 12.5 kN	Modulus 27.5 kN	Modulus 40 kN	Modulus 50 kN
Wearing Course + Base	1	160	200	250	250	300
Base	2	150	60	70	70	70
Embankment	3	301	15	15	15	15
Silt 1.	4	100	10	15	10	10
Silt 2.	5	89	10	10	10	10
Frozen ground	6		500	800	800	1000

Table 1-3: Back calculated moduli values at four load levels measured at Kemijärvi test site 6.6.2003.

21.7.2003	**LINE 3.**	**LEFT LANE OUTER WHEEL PATH**				
Road Structure	Layer	Thickness (mm)	Modulus 12.5 kN	Modulus 27.5 kN	Modulus 40 kN	Modulus 50 kN
Wearing Course + Base	1	151	400	400	400	400
Base	2	150	300	300	200	200
Embankment	3	239	70	70	60	60
Silt 1.	4		150	150	130	130
Silt 2.	5					
Frozen ground	6					

21.7.2003	**LINE 2.**	**ROAD CENTER**				
Road Structure	Layer	Thickness (mm)	Modulus 12.5 kN	Modulus 27.5 kN	Modulus 40 kN	Modulus 50 kN
Wearing Course + Base	1	151	400	400	400	400
Base	2	150	400	400	400	400
Embankment	3	239	70	70	70	70
Silt 1.	4		70	70	60	60
Silt 2.	5					
Frozen ground	6					

21.7.2003	**LINE 1.**	**RIGHT LANE OUTER WHEEL PATH**				
Road Structure	Layer	Thickness (mm)	Modulus 12.5 kN	Modulus 27.5 kN	Modulus 40 kN	Modulus 50 kN
Wearing Course + Base	1	160	450	450	500	500
Base	2	150	450	450	450	500
Embankment	3	301	100	100	70	70
Silt 1.	4		140	140	130	120
Silt 2.	5					
Frozen ground	6					

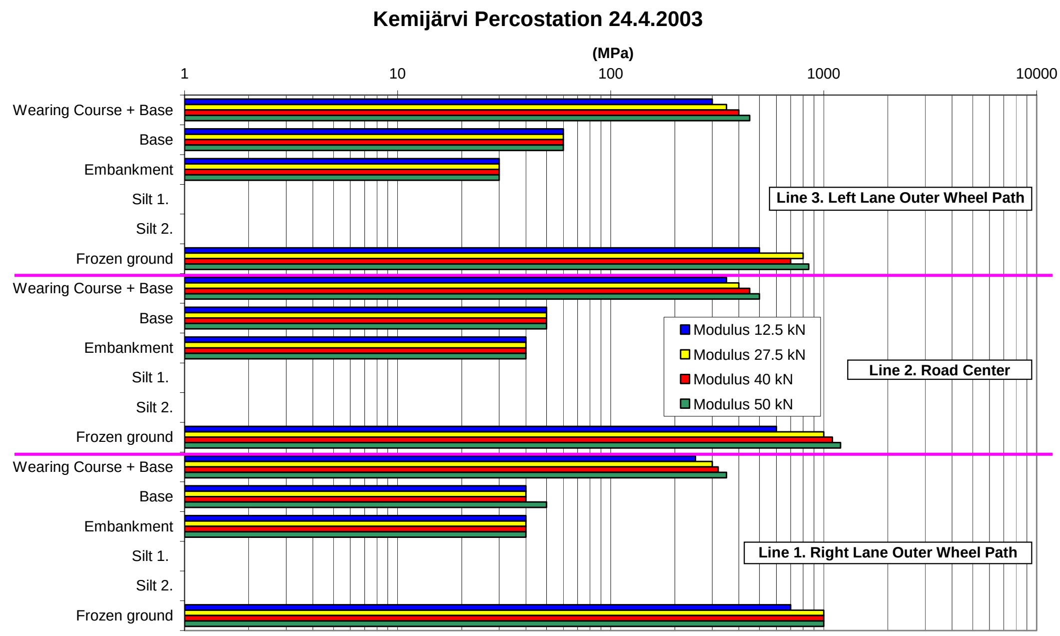

Figure 1-1. Moduli values at four different load levels at Kemijärvi Percostation 24.4.2003.

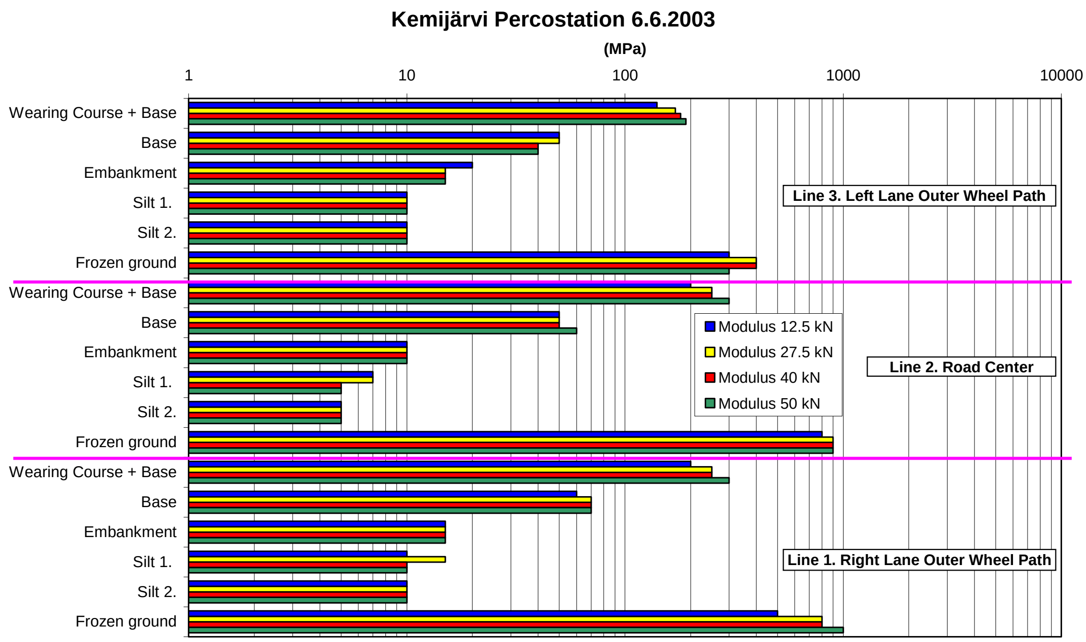

Figure 1-2. Moduli values at four different load levels at Kemijärvi Percostation 6.6.2003.

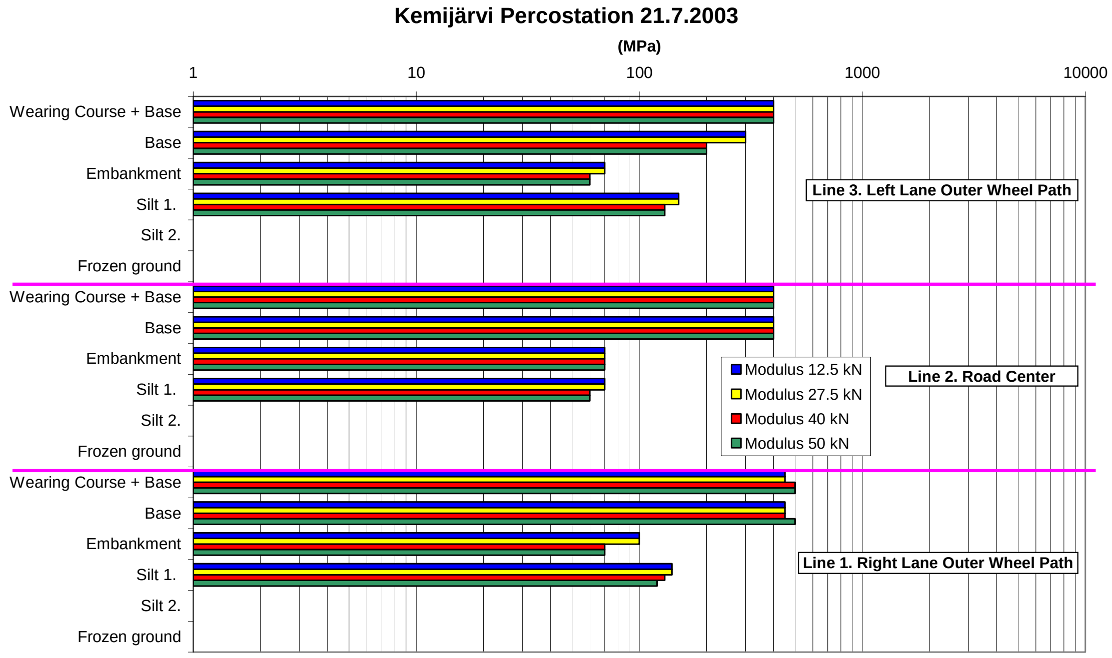

Figure 1-3. Moduli values at four different load levels at Kemijärvi Percostation 21.7.2003.

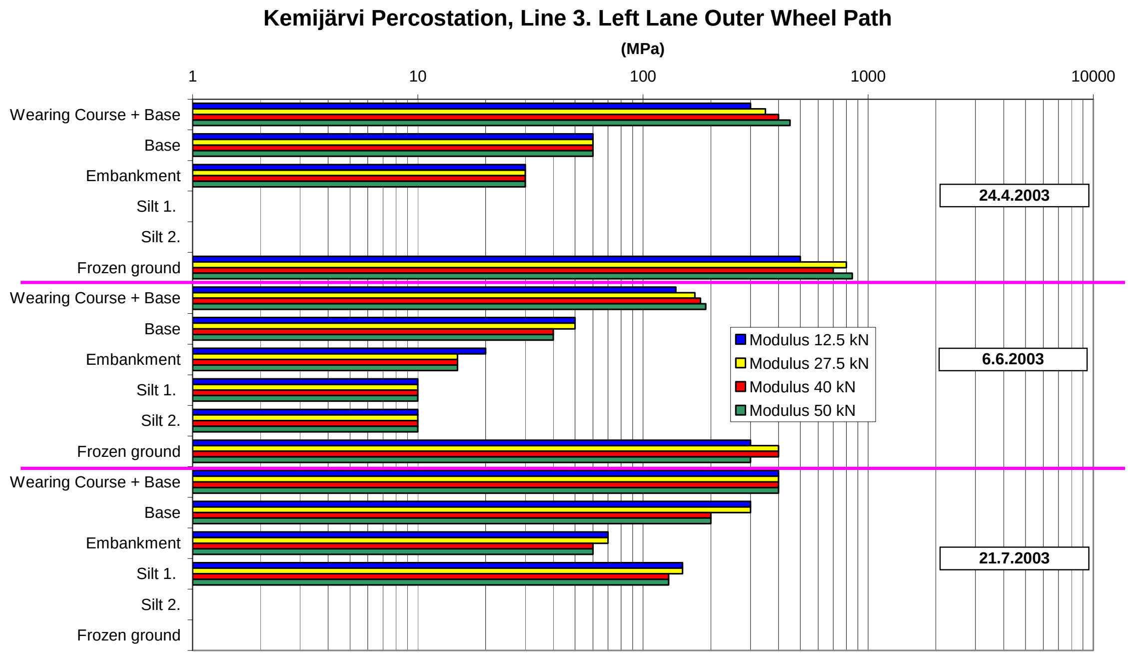

Figure 1-4. Variations in moduli values at Kemijärvi Percostation in spring and summer 2003, left lane, outer wheel path.

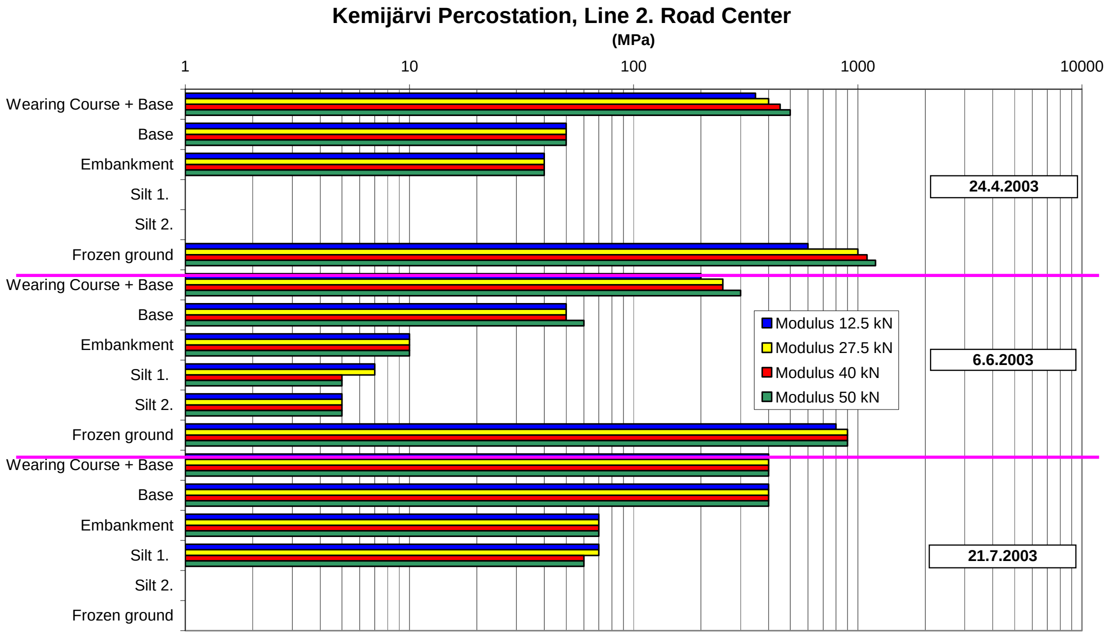

Figure 1-5. Variations in moduli values at Kemijärvi Percostation in spring and summer 2003, road center.

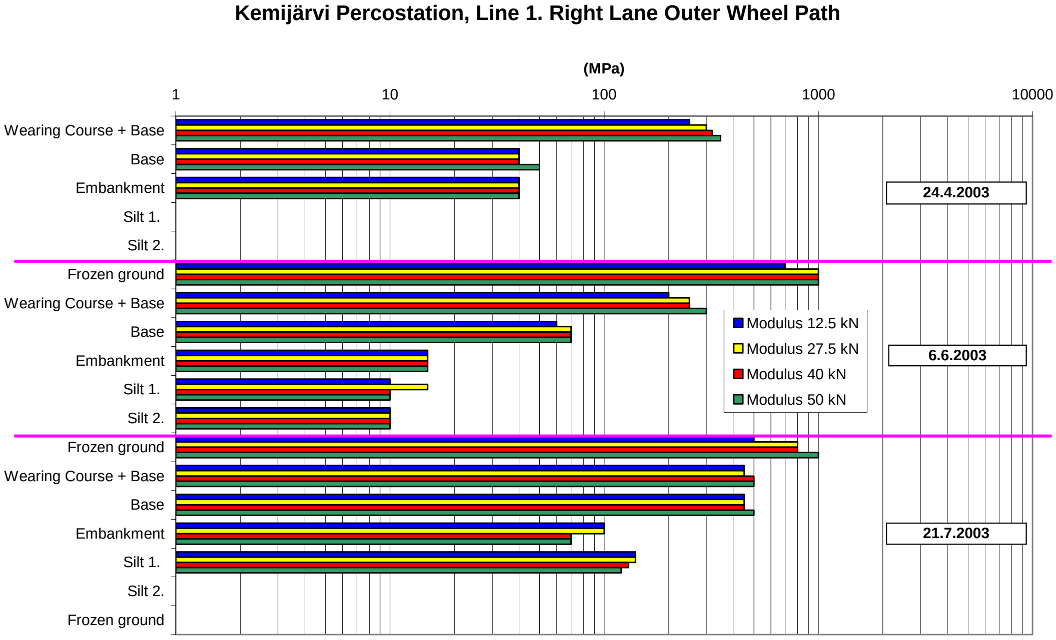

Figure 1-6. Variations in moduli values at Kemijärvi Percostation in spring and summer 2003, right lane, outer wheel path.

Roadex Publications

ROADEX II

- ROADEX II - Focusing on Low Volume Roads in the Northern Periphery DVD
- User Perspective to ROADEX II Test Areas' Road Network Service Level
- Permanent deformation
- New material treatment techniques
- Managing spring thaw weakening on low volume roads
- Socio-economic impacts of road conditions on low volume roads
- Dealing with bearing capacity problems on low volume roads constructed on peat
- Drainage on low traffic volume roads
- Environmental guidelines
- Environmental guidelines, pocket book
- Road management policies for low volume roads – some proposals
- Structural Innovations
- Monitoring, communication and information systems & tools for focusing actions

ROADEX I

- Roadex Multi-media CD-ROM
- Road Condition Management of Low Traffic Volume Roads in the Northern Periphery
- Winter Maintenance Practice in the Northern Periphery,
- Generation of 'Snow Smoke' behind Heavy Vehicles

ROADEX II
NORTHERN PERIPHERY

Roadex II Lead Partner: The Highland Council, Transport, Environmental & Community Service, HQ, Glenurquhart Road, Inverness IV3 5NX Scotland.

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