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# DESIGN AND REPAIR OF ROADS SUFFERING SPRING THAW WEAKENING

**Executive Summary** 

Design and Repair of Roads Suffering Spring Thaw Weakening EXECUTIVE SUMMARY March 2006

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## PREFACE

The report that follows is an executive summary of the 2005 ROADEX II report "Managing Spring Thaw Weakening On Low Volume Roads - Problem Description, Load Restriction Policies, Monitoring And Rehabilitation" by Timo Saarenketo and Saara Aho of Roadscanners Oy.

It aims to be a working manual, concentrating on the rehabilitation methods and practices that should be carried out for low volume roads suffering from problems related to seasonal changes, especially spring thaw weakening.

The report is not intended to replace the many excellent reference works and text books available on the subject but it is hoped that the summaries that are outlined will give the reader a greater understanding of the issues and solutions for this recurring seasonal problem.

The report was written by Saara Aho and Timo Saarenketo from Roadscanners Oy, Finland. Ron Munro, project manager of the ROADEX III Project, checked the language. Mika Pyhähuhta of Laboratorio Uleåborg designed the report layout.

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# **Chapter 1. INTRODUCTION**

### **1.1 THE ROADEX PROJECT**

The ROADEX Project is a technical cooperation between roads organisations across northern Europe that aims to share roads related information and research between the partners.

The Project was started in 1998 as a 3 year pilot co-operation between the roads districts of Finnish Lapland, Troms County of Norway, the Northern Region of Sweden and The Highland Council of Scotland and this was later followed up with a second project, ROADEX II, from 2002 to 2005.



Figure 1: The Northern Periphery Area and Roadex II partners

The partners in the ROADEX II Project comprised public road administrations, forestry organizations, forest companies and haulage organizations from regions in the Northern Periphery. These were The Highland Council, Forest Enterprise & The Western Isles Council from Scotland. The Region Nord of The Norwegian Public Roads Administration and The Norwegian Road Haulage Association, The Northern Region of The Swedish Road Administration and The Lappi and Keski-Suomi Regions of The Finnish National Roads Administration. (These latter Finnish Regions also received aid from their local forest industry organisations of Metsähallitus, Lapin Metsäkeskus, Metsäliitto & Stora-Enso.)

The goal of the project was to develop ways for interactive and innovative road condition management of low traffic volume roads integrating the needs of local industry, society and roads organisations. 8 formal reports were published together with a project DVD and full copies of all reports are available for download at the ROADEX web site at <u>www.roadex.org</u>.

This Executive Summary report is one of 8 summaries that have been prepared under the direction of the ROADEX III project (2006-2007), a new Project where the named project Partners above were joined by the additional Northern Periphery Partners of the Municipality of Sisimiut, Greenland, The Iceland Public Roads Administration and the Finnish Road Administration Region of Savo-Karjala.

# 1.2 DESIGN AND REPAIR OF ROADS SUFFERING SPRING THAW WEAKENING

Seasonal changes, freeze-thaw cycles and the damage they cause are the most significant factors affecting the road condition of northern cold climate road networks in Europe, Asia and North America. Freeze-thaw processes also cause major problems in high elevated areas in countries with warmer climates. 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%.

Frost damage exhibits in roads as uneven frost heave and longitudinal and transverse cracking, but above all as softening of the road structure and permanent deformation during the thawing period. In the worst scenario driving on these roads can be impossible. Usually thaw weakening damage is the biggest problem on "unbuilt" gravel roads but it also causes major problems on paved roads and especially on weak roads with a surface dressing pavement.

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) load restrictions and 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) co-operation with transportation organizations using heavy vehicles.

Traditionally road administrators have endeavoured to prevent spring thaw damage by implementing load restrictions or even closing the road. The use of spring load restrictions increases the pavement lifetime but at the same time load restriction measures also incur major extra costs for industries using heavy transport vehicles. For instance 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).

Thus, the best and most sustainable solution for managing thaw weakening problems is to strengthen and rehabilitate the weak road sections. However this can, and should, only be done if the road region has enough resources to take appropriate measures that will function over the long term. Major mistakes have 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. This report concentrates on presenting the strengthening processes and methods for weak road sections based on the research work done during the ROADEX II – subprojects "Managing Spring Thaw Weakening on Low Volume Roads" (Saarenketo and Aho 2005) and "Permanent Deformation" (Dawson and Kolisoja 2005) and also on the report "Design and Rehabilitation of Spring Thaw Weakened Road Sections" (Aho et al. 2005b) prepared for Finnish Road Administration (Finnra). The goal for this report is to provide a practical guide that addresses the needs of the local roads engineer, designer etc. and presents a systematic step-by-step analytical approach for design and repair of roads suffering spring thaw weakening. A classification system for spring thaw damaged road sections, as well as the basic theory relating on the spring thaw weakening, is also presented providing better understanding the process behind the problems. The report also provides a short review for rehabilitation structures and their suitability for repairing different types of damages. Finally, the report handles the general aspects relating to the quality assurance and functionality control of the rehabilitated roads.

More policies and techniques for spring thaw weakening management are discussed in ROADEX II project report "Managing Spring Thaw Weakening on Low Volume Roads" written by Saarenketo and Aho (2005).

# Chapter 2. Thaw Weakening – Short Description

## 2.1 FACTORS AFFECTING THAW WEAKENING

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 layers of the road thaw during the spring. Launonen et al. (1995) listed the following factors as being necessary for the appearance of spring thaw weakening:

- the road and/or subgrade freezes
- the material is frost susceptible
- the freezing front has enough water available
- during the thawing period the water, released by the melting segregation ice, stays in the road structure or subgrade soil, thus weakening the structure
- the road is subject to loads during the thawing period.

If any one of these factors is absent there is no risk of spring thaw damage. In countries with warmer climates (e.g., Scotland) frost thaw weakening is usually related to weakening of the road after daily freeze-thaw cycles. The processes behind thaw weakening are described in more detail in the ROADEX II project report "Managing Spring Thaw Weakening on Low Volume Roads" (Saarenketo and Aho 2005).

The factors affecting the development of thaw weakening can be divided into loading, environmental and design related factors as presented in Table 2.1. The design related factors are the local factors related to the location of the road and its surroundings that have an influence on frost action, on the amount of frost heave and on the dissipation of melting water. All of the factors presented in Table 2.1 have some effect on their own and combine with the others to jointly increase their influence. Maintenance measures and the bearing capacity of the road shoulders can also affect the degree of difficulty of spring thaw damage in addition to seasonal effects.

LOADING	ENVIRONMENT	DESIGN RELATED
The amount of heavy traffic The magnitude of the axle loads The magnitude of the tyre pressures Time between traffic loads	Weather and hydrological factors - Temperature - Groundwater level - Precipitation - Frost (ice lenses)	Drainage - The topography of the road and its surroundings - Drainage structures Road structure - Thickness, quality and mixing Subgrade - Subgrade soil and its frost resistance

## 2.2 SPRING THAW WEAKENING PHASES

The ROADEX II spring thaw monitoring results identified four different time phases for spring thaw weakening with unique features requiring separate classifications. These occur in a chronological order and the need for load restrictions, for instance, in each phase is strongly dependent on the increase, or lack of it, in moisture content and stiffness of the road during the previous period. The four phases are:

- 1) the freeze-thaw cycles phase,
- 2) the surface thaw weakening phase,
- 3) the structural thaw weakening phase and
- 4) the subgrade thaw weakening phase.

A common factor in all of these phases 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. In Scotland, and in other countries with warmer climates, the main problem is not spring thaw weakening but the repeated freeze-thaw cycles that occur daily during the winter. In those areas the freeze-thaw cycles phase is usually the only phase present.

The four spring thaw weakening phases are presented in greater detail in the ROADEX II report "Managing Spring Thaw Weakening on Low Volume Roads". They can be used in monitoring and communication terminology to describe the status of spring thaw and they can also be used in the decision making process for the implementation, or removal, of load restrictions. Also, as a part of the rehabilitation design and problem analysis, it is important to identify the particular phases that are causing the problems. This is an important factor in determining the appropriate repair methods.

### 2.3 SPRING THAW WEAKENING SITE CLASSIFICATION

The ROADEX II report "Managing Spring Thaw Weakening on Low Volume Roads" (Saarenketo and Aho 2005) proposes a system of classifying spring thaw damage sites, and their causes, by means of topographical and subgrade conditions and damage descriptions. The criteria used are:

- subgrade soil
- topography of road and its surroundings
- severity of damages
- frequency of damages

Each class considered is sub-divided into three (I-III) subclasses depending on the severity and frequency of the damages. The subclasses are:

- I. Mild problems, where spring thaw problems are not severe and do not occur annually
- II. Medium problems, where light or medium spring thaw problems are found almost every spring
- III. Severe problems, where medium or severe structural spring thaw problems have been monitored annually

By using this system, spring thaw damage sites can be divided into the 27 damage classes presented in Table 2.2. The general description of each problem site is provided in the ROADEX II report "Managing Spring Thaw Weakening on Low Volume Roads" (Saarenketo and Aho 2005). This classification system is recommended for use in diagnosing the basic problem and selecting the optimum rehabilitation method.

SUBGRADE SOIL	TOPOGRAPHY	SEVERITY AND FREQUENCY OF DAMAGES	DAMAGE CLASS
		Mild	A.I
	sloping ground	Medium	A.II
		Severe	A.III
		Mild	B.I
moraine	Flat and even area	Medium	B.II
		Severe	B.III
		Mild	C.I
	hummock	Medium	C.II
		Severe	C.III
		Mild	D.I
	sloping ground	Medium	D.II
		Severe	D.III
	flat and even area	Mild	E.I
clay and silt		Medium	E.II
		Severe	E.III
		Mild	F.I
		Medium	F.II
	vancy	Severe	F.III
	mainly on flat and	Mild	G.I
peat	and low lving	Medium	G.II
	valley	Severe	G.III
		Mild	H.I
bedrock	mainly on sloping	Medium	H.II
	ground	Severe	H.III
	other spring thaw	Mild	1.1
	are not related to a	Medium	1.11
	subgrade soil	Severe	1.111

	Table 2.2.	Classification	system a	for	spring	thaw	weakening	damage sites	
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# Chapter 3. Rehabilitation Process

The major problem in most projects involving the strengthening of low volume roads and/or improving their functional condition has been that the structural solutions used have mainly been selected on a hit-and-miss basis and thus are only based on the experience of the local engineers. This has led, in many cases, to the use of a preferred single structural solution for every problem encountered on the road network which, in some cases, will work and in others not. However, the problem is that spring thaw damage mechanisms are complex and as such different spring thaw weakening sites require different rehabilitation solutions. For this reason sufficient resources should always be allocated to the diagnosis of the problems underlying the damaged road sections.

The design and rehabilitation of spring thaw weakened road sections should be considered as a process lasting 2 - 4 years (see Figure 3.1). This process should not end after the execution of the first rehabilitation structures or even after their quality assurance. The rehabilitation process should be continued with systematic control and monitoring of the rehabilitated roads together with problem diagnosis of any new damage and rehabilitation measures.



Figure 3.1. The design and rehabilitation process for spring thaw weakened road sections.

As a part of the rehabilitation process it is important to evaluate the risk of deterioration in each road section. This should be done in order to identify those sections where deterioration is not present at the time of the survey but which could have a higher risk of failures after the removal of the load restrictions – if and when they are removed. In this risk analysis the road is divided to discrete sections based on their risk class for failure. A good example of a risk analysis made for a road is that of the B871 between Kinbrace and Syre in Scotland. This can be found in the ROADEX II report "Monitoring, Communication and Information Systems & Tools for Focusing Actions" (Saarenketo 2005).

When executing the rehabilitation process presented in Figure 3.1 it is important to bear in mind that the data, once collected on the road network, can be utilized for many years not only in the design and repair of spring thaw damaged road sections but also in monitoring how well the repaired road sections are working. Reliable monitoring data is extremely important for learning how to identify weak road sections that will be damaged shortly after rehabilitation once load restrictions have been removed - so that in future they can be strengthened during the first rehabilitation phase. In addition, the monitoring data collected will give valuable information about the service life of the different rehabilitation structures and their suitability for different damage classes.

# Chapter 4. Research and Analysis of Spring Thaw Weakened Road Sections

### 4.1 RESEARCH METHODS FOR LOW VOLUME ROADS

The first stage in selecting an optimum structural solution for a road section is to collect enough reliable information about the existing road, its condition and its structures, and about the geological and drainage conditions in the area. For this task several methods, such as Dynamic Cone Penetrometer testing (DCP), bearing capacity measurements, Ground Penetrating Radar (GPR), profilometer techniques for rutting and roughness information, visual evaluation data regarding drainage condition and taking samples from the road structures and subgrade soil can be used. Visual distress evaluation data and other reference information, such as video images of the road, can also be useful. All of this data should be collected in a way that their precise location on the road is known.

Table 4.1 presents suitable research methods for low volume roads, the information they offer and the best execution time for each method. The timing of these surveys is very important to obtain reliable and representative data. Further details regarding these techniques are given in the ROADEX II project reports, such as "Dealing with Bearing Capacity Problems on Low Volume Roads Constructed on Peat" (Munro 2004), "Monitoring, Communication and Information Systems & Tools for Focusing Actions" (Saarenketo 2005) and "Managing Spring Thaw Weakening on Low Volume Roads" (Saarenketo and Aho 2005).

RESEARCH METHOD	INFORMATION	EXECUTION TIME
Ground Penetrating	Frost line penetration depth	Winter – frozen ground
Radar, GPR	Ice lenses	
	Road structures – thickness and	
	mixing	
	Location of bedrock and peat	
	Location of frost susceptible soils	
	/ differential frost heave	
	Pavement and wearing course	Summer – unfrozen
	thickness	ground
	Roads structures – thickness and	
	mixing	
	Subgrade soil estimation and	
	quality	
	Location of bedrock and peat	

Table 4.1. Research methods for low volume roads.

		-
Sampling / Drill Cores	Material properties - road structure and subgrade Subgrade soil estimation Pavement and wearing course thickness Road structures – thickness Reference for other research methods	Summer – unfrozen ground
Digital Video	Topography of road and its surroundings Functionality of drainage system Visual distress evaluation	Bright time, without snow
Site Visit	Location of spring thaw weakened sections Visual evaluation for drainage condition	Spring – most of the melting water floating around
Falling Weight Deflectrometer, FWD	Bearing capacity Subgrade soil estimation Location of bedrock	Late summer and early autumn (August – September)
Dynamic Cone Penetrometer, DCP	Road structures – thickness Road structures / subgrade soil – shear strength Frost line penetration depth	Spring or summer
Accelerometer / Profilometer Techniques	Paved roads - rutting and roughness	Summer
	Gravel roads - differential frost heave	Winter
Databases (if any) / History and Follow-up Data - Spring thaw damages - Pavement distress data	Location of road sections suffering spring thaw weakening Spring thaw damages – severity and frequency Rehabilitation structures – thickness, location, quality of used materials, durability	

It will not always be cost-effective of course to use all of the methods presented in Table 4.1 and it will be necessary to select the most appropriate method(s) for each site. After the survey, the next step in the rehabilitation process is the integrated survey analysis (Chapter 4.2) which is used not only for identifying the sections suffering spring thaw weakening but also for diagnosing the underlying problems. In Chapter 4.3 an operations model for research and analysis of spring thaw weakened roads is provided. The model presents an example of one combination of surveys that could be used during the rehabilitation process as well as the conclusions made.

When discussing surveys and rehabilitation measures on low volume roads it should be understood that any investment made is not just a "single-use" investment. Data once collected on a road network can be utilized for many years not only in the design and repair of spring thaw damaged road sections but also in the functionality control of repaired roads. Reliable survey and follow-up data can be extremely important for learning to identify those weak road sections which are likely to be damaged shortly after road rehabilitation following the removal of load restrictions. In addition, the collected follow-up data can give valuable information about the service life of different rehabilitation structures. Thus, the data collected is valuable for later usage.

## 4.2 INTEGRATED ANALYSIS OF SURVEY DATA

The survey data collected can now be used for making a risk analysis of the identified road sections. In the risk analysis the road should be divided into discrete sections based on the integrated analysis of the survey data and the following key elements affecting the lifetime performance of the road (see Saarenketo 2001):

- drainage condition,
- overall wearing course / pavement / other bound structures condition,
- assessment of the condition of unbound road structures,
- fatigue related to frost action in subgrade,
- subgrade damage related to very weak subgrade (silt, peat), and
- local damage of the surveyed road, such as settlements, culverts etc.

Using these features and risk analysis, the problem sections, and the sections with potential to become a problem in the near future, can be identified. These sections can then be given a detailed problem diagnosis in order to classify the type of structural defects and their causes. The classification system presented in Chapter 2.3 is recommended for this.

Figure 4.1 provides an example of the integrated analysis of survey data using Road Doctor software made by Roadscanners. In this case the survey data consisted of the following data:

- ground penetrating radar, GPR (data 1 and 2)
- spring thaw damages history data (data 3)
- roughness information measured by accelerometer (data 4)
- bearing capacity measurements made by falling weight deflectometer, FWD (data 5)
- digital video and GPS (data 7)
- basemap (data 8).

Using integrated analysis the damage sites can be classified (data 6 in Figure 4.1) using the classification system presented in Chapter 2.3. This classification can also be considered as a basic diagnosis tool for the type of structural defects and their causes. Once the diagnosis has been made, the road survey data and other information can be used to select the most suitable rehabilitation measure(s) for each particular type of road defect in each road section (Saarenketo 2001).



Figure 4.1. An example of the integrated analysis method produced by Road Doctor –software.

By knowing the precise location of the defects and implementing rehabilitation measures based on their causes, unnecessary construction work and incorrect rehabilitation actions can be avoided (Saarenketo 2001). Furthermore detailed risk analysis can identify those road sections with a reasonable life expectancy that do not need attention and allow funds to be targeted on effective measures in those sections of road that are in need of repair. The strengthening methods for spring thaw damaged road sections are described in Chapter 5.

# 4.3 OPERATIONS MODEL FOR RESEARCH AND ANALYSIS OF SPRING THAW WEAKENED ROADS

An example of a typical step-by-step procedure for surveying and analysing a road for rehabilitation measures is presented below. The steps listed are scheduled to gather sufficient reliable and representative information on the features affecting spring thaw weakening. The procedure is applicable both for gravel and paved roads. Additional steps using further surveys can be added if needed.

#### A. GPR Measurements - Winter

Winter Ground Penetrating Radar (GPR) surveys are recommended for gravel roads as GPR is not always effective in summer where dust binding

agents are used. A system employing a 400 – 500 MHz ground coupled antenna is used to measure road structure layer thicknesses and any interlayer mixing. GPR data collected on frozen ground can also provide information on soil frost penetration depth and ice lenses and, in addition, bedrock and peat sites can be located precisely. Usually one longitudinal GPR section provides enough information for low volume roads but if more accurate data is required more lanes can be measured.

Site measurements of frost heave can quickly identify damage related to spring thaw weakening but they can also be quite expensive to carry out. Digital video and GPS data collected at the same time as GPR measurements are a cheaper and effective substitute for frost heave measurements (Figure 4.2). The location of differential frost heave can be approximately determined using digital video recorded in winter. Accelerometer and profilometer techniques can also be used if more precise data is needed.



Figure 4.2. The digital video and GPS installed on a GPR measurement car.

#### B. Location and History of Problem Sites

This section considers how to identify road sections suffering spring thaw weakening. These include both new damage sites as well as repaired sites that still suffer spring thaw weakening. Risk analysis of other road sections not exhibiting deterioration but which have a high risk of failures after the removal of load restrictions should also be carried out.

This identification can be carried out using historical data, and/or follow-up data, collected from problem roads. If such databases are not available, it is recommended that problem road sections be visually monitored for 1-2 years to obtain good data. The GPR data collected in stage A above is also valuable for this risk analysis. The most valuable data for gravel roads are

spring thaw damage observations and for paved roads roughness and rutting data from a profilometer. If this type of monitoring is not possible due to time schedules, then pavement distress data analysed from digital videos and interviews made among the maintenance personnel and road users can be used to evaluate failure development and location.

#### C. Integrated Analysis of Survey Data

After identifying the problem sections the initial problem diagnosis (Chapter 2.3) and first proposal for strengthening methods can be made. The description of the integrated analysis technique used here is given in Chapter 4.2. It is important that the first diagnosis of the reasons behind the damage is done in this phase so that these results can be verified later on site.

#### D. Site Visit - Spring

The spring site visit is made to verify the locations of the problem road sections and any new sections suffering from spring thaw weakening identified. The initial problem diagnosis can also be confirmed and the first proposal for strengthening methods checked. This site visit is best scheduled for the spring when most of the ditches are full of melting water and the road is in its weakest condition. This is also the best time to do the drainage condition analysis as well as to identify those sections with weak bearing capacity on the road shoulders.

The condition of the road drainage should be visually checked in the problem sections at this time and throughout the road length. This should be done as drainage improvement will prevent, or delay, the development of other road defects. GPR data can provide useful information on the condition of the drainage in addition to visual evaluation at this time. It is often useful to collect digital video during this site visit so that the visual data can be evaluated again afterwards if required. A two-camera system digital video can be used, one camera mapping the road while the other is directed at the ditch.

#### E. GPR Measurements - Summer

These GPR measurements are carried out in summer when the road structure and subgrade are completely unfrozen. A 1.0–2.2 GHz antenna is used to find out the thickness of wearing course/pavement and base layers (Figure 4.3). 'Rutting mode' (see Dawson and Kolisoja 2005) can also be classified at this time through GPR using a 400 MHz antenna across the road cross-sections. Drill cores can be taken to calibrate the GPR interpretations. If the problems are thought to be related to the unbound materials appropriate laboratory analysis of material quality and moisture susceptibility should be

carried out. Laboratory analysis can also be used, for example, to indicate if the surface thaw weakening is related to the quality of the wearing course. One parameter that has been found to be effective when evaluating the quality of unbound road structures is the dielectric value. The use and properties of dielectric value are described in ROADEX II project report "Material Treatment" (Kolisoja and Vuorimies 2005).



Figure 4.3. The GPR measurement car with 1 GHz horn antenna on front.

An analysis of the wearing course of gravel roads can also be carried out using the GPR measurements.

#### F. <u>Bearing Capacity Measurements – Late Summer or Early Autumn</u>

Bearing capacity measurements on gravel roads are mostly used to confirm the GPR interpretation, the assessment of the subgrade soil type and the evaluation of the quality of the unbound road structures. Falling weight deflectometer (FWD, Figure 4.4) is the best technique to use if the road problems are related to weak subgrade conditions. A dynamic cone penetrometer (DCP) can also be used if the maximum grain size of the aggregates is not too big. FWD measurements, together with the mode of rutting, can give good information on the source of any bearing capacity problems. The mode of the rutting should be classified in this phase if not classified earlier.



Figure 4.4. The KUAB falling weight deflectrometer. (Aho 2004)

FWD data together with the road structure thickness data, imported from the GPR survey results, can also be used to calculate the surface bearing capacity of paved roads. Material moduli values are first determined using 'back calculation' software. Following this, traditional Odemark dimensioning can be used to give an initial bearing capacity assessment for the road structure. This can be used in evaluating the magnitude of the strengthening measures. Special indexes like the Surface Curvature Index (SCI) and the Base Curvature Index (BCI) can also be used for bearing capacity analysis.

It should be kept in mind however, when evaluating the risk for permanent deformation that FWD data collected during the dry summer months can often give overly optimistic bearing capacity values due to suction properties. In general it can be stated that if the bearing capacity values are reasonable, the road may still have problems with frost and permanent deformation – but if these measured parameters are poor, then the road is always in poor structural condition. Bearing capacity values are most repeatable and comparable if the data collection is carried out in late summer or early autumn when the moisture content is more "normal".

#### G. Detailed Problem Diagnosis and Design for Rehabilitation

In this final stage the basic diagnosis of the problems carried out in stage C is updated with help of the data collected during stages D-F. The road survey data gathered, and other information, is used to design the most suitable rehabilitation measures for each particular type of road defect in each road section. In this stage, it is recommended that the design strategy for preventing permanent deformation as presented in the ROADEX II report "Permanent Deformation" (Dawson and Kolisoja 2005) is used. Layer thicknesses can also be defined by traditional dimensioning using Odemark's formulas. In all of the above it is important that all survey and design data, and after construction the quality assurance data as well, is collected and saved systematically for the use of durability control of repaired roads. The data saved can also be used to analyse the effects of the rehabilitation measures carried out and be useful initial data for future rehabilitation design. The data is recommended to be saved for future use linked in a way which enables its' simultaneous assessment.

# Chapter 5. Spring Thaw Damage Strengthening

### 5.1 GENERAL

The problem with spring thaw damage strengthening is that, as described in Chapter 3, new failures often arise in new places after the original thaw weakened areas have been repaired and heavy traffic restarts following the removal of load restrictions. If this is not understood, and addressed, it can create a poor perception in eyes of road users and it is therefore important to inform the users that the repair project underway is a 2-4 years rehabilitation process that aims to improve the whole road. This means that all measures, drainage improvement as well as other maintenance actions, need to be carried out for the whole length of the road at the same time as the rehabilitation measures. Additionally monitoring of spring thaw damage should not end after the first repair phase.

The risk of failures due to heavy construction traffic during the strengthening works can be reduced by good timing and practices. Ideally spring thaw damage strengthening measures should be carried out in summer when the road structures are dry and strong enough to sustain the loading caused by the construction works. Loadings on the road during rehabilitation can be reduced by using part loaded vehicles and allowing sufficient recovery times in the road structures between the passage of trucks. The theory behind the recovery time of roads is discussed more detailed in ROADEX II project report "Managing Spring Thaw Weakening on Low Volume Roads" (Saarenketo and Aho 2005).

## 5.2 LIFECYCLE COSTS OF REHABILITATION STRUCTURES

Strengthening of spring thaw damage sites should only be done if the road region has enough resources to execute measures that will function over the long term. Major mistakes have been made when road sections have been strengthened using insufficient structures that have been too weak. Aho (2004) did some calculations regarding the lifetime costs of the standard repair structures for gravel roads and the results confirmed that there is not a single standard economical structural solution for repairing all spring thaw damage. Depending on the prevailing conditions at a spring thaw damage site the lifetime of a standard structure may be shorter and thus lifecycle costs higher.

According to the results of analysis, the thinnest structural options are more sensitive to lifetime variation. If the new structure is not strong enough for the appearing spring thaw damages, the lifetime of the structure will be shorter and the costs per year will increase rapidly. This lifetime shortening is not so common with thicker structures and for this reason thicker structures (400 - 500 mm) should be favoured when repairing severe spring thaw damage.

If adequate funding is not available for strengthening road structures, the most effective method to combat spring thaw problems is to improve the drainage system and keep it maintained in good working order. Different drainage techniques as well as their life cycle costs analysis have been reported in great detail in the ROADEX II project report "Drainage on Low Volume Roads" (Berntsen and Saarenketo 2005) and further in the ROADEX III project drainage reports.

## 5.3 REHABILITATION STRUCTURES FOR GRAVEL ROADS

Gravel road rehabilitation and strengthening design is relatively straightforward when the cause of the damage is well defined. The determination of rehabilitation structures on gravel roads is usually done based on the features described in Chapter 2.3 and the most frequently used rehabilitation methods on gravel roads are presented in Table 5.1. Sketches and repair methods for each rehabilitation structure is provided on treatment cards which can be found in Appendix 1. When studying these structures it should be kept in mind that they are the basic solutions and the special features of each damage site should be considered when carrying out the rehabilitation. It is also important not to forget the importance of an effective drainage system for the functionality of the rehabilitated structure. Drainage improvement should always be carried out at the same time, or even earlier, as strengthening methods.

	I BASIC STRUCTURE
1.	removal of old wearing course
2.	subgrade homogenization 300 mm (if required)
3.	geotextile, filter cloth
4.	base course 200 – 300 mm
5.	wearing course 100 mm
	II STEEL REINFORCEMENT
1.	removal of old wearing course
2.	removal of old material 100 – 150 mm (if required)
3.	geotextile, filter cloth
4.	base course 100 mm
5.	steel reinforcement
6.	base course 200 mm
7.	wearing course 100 mm
	III RAISING ROAD ALIGNMENT

Table 5.1.	The construction	process for gravel	l road rehabilitation structures.
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<ul> <li>2. subgrade homogenization 300 mm (if required)</li> <li>3. geotextile, filter cloth</li> <li>4. sub base ≥ 200 mm</li> <li>5. base course 200 mm</li> <li>6. wearing course 100 mm</li> <li>IV SOIL REPLACEMENT</li> <li>1. removal of old wearing course</li> <li>2. removal of old material ≥ 600 mm</li> <li>3. geotextile, filter cloth</li> <li>4. filter bed ≥ 300 mm</li> <li>5. base course 200 – 300 mm</li> <li>6. wearing course 100 mm</li> <li>V STRENGTHENING ROAD SHOULDERS</li> <li>several methods such as <ul> <li>soil replacement on road shoulders</li> <li>widening inner slopes</li> </ul> </li> <li>VI OTHER STRUCTURES</li> <li>several methods such as <ul> <li>stabilization</li> <li>frost insulation etc.</li> </ul> </li> </ul>	1.	removal of old wearing course
<ul> <li>3. geotextile, filter cloth</li> <li>4. sub base ≥ 200 mm</li> <li>5. base course 200 mm</li> <li>6. wearing course 100 mm</li> <li>IV SOIL REPLACEMENT</li> <li>1. removal of old wearing course</li> <li>2. removal of old material ≥ 600 mm</li> <li>3. geotextile, filter cloth</li> <li>4. filter bed ≥ 300 mm</li> <li>5. base course 200 – 300 mm</li> <li>6. wearing course 100 mm</li> <li>V STRENGTHENING ROAD SHOULDERS</li> <li>several methods such as <ul> <li>soil replacement on road shoulders</li> <li>widening inner slopes</li> </ul> </li> <li>VI OTHER STRUCTURES</li> <li>several methods such as <ul> <li>stabilization</li> <li>frost insulation etc.</li> </ul> </li> </ul>	2.	subgrade homogenization 300 mm (if required)
<ul> <li>4. sub base ≥ 200 mm</li> <li>5. base course 200 mm</li> <li>6. wearing course 100 mm</li> <li>IV SOIL REPLACEMENT</li> <li>1. removal of old wearing course</li> <li>2. removal of old material ≥ 600 mm</li> <li>3. geotextile, filter cloth</li> <li>4. filter bed ≥ 300 mm</li> <li>5. base course 200 – 300 mm</li> <li>6. wearing course 100 mm</li> <li>V STRENGTHENING ROAD SHOULDERS</li> <li>several methods such as <ul> <li>soil replacement on road shoulders</li> <li>widening inner slopes</li> </ul> </li> <li>VI OTHER STRUCTURES</li> <li>several methods such as <ul> <li>stabilization</li> <li>frost insulation etc.</li> </ul> </li> </ul>	3.	geotextile, filter cloth
<ul> <li>5. base course 200 mm</li> <li>6. wearing course 100 mm</li> <li>IV SOIL REPLACEMENT</li> <li>1. removal of old wearing course</li> <li>2. removal of old material ≥ 600 mm</li> <li>3. geotextile, filter cloth</li> <li>4. filter bed ≥ 300 mm</li> <li>5. base course 200 – 300 mm</li> <li>6. wearing course 100 mm</li> <li>V STRENGTHENING ROAD SHOULDERS</li> <li>several methods such as <ul> <li>soil replacement on road shoulders</li> <li>widening inner slopes</li> </ul> </li> <li>VI OTHER STRUCTURES</li> <li>several methods such as <ul> <li>stabilization</li> <li>frost insulation etc.</li> </ul> </li> </ul>	4.	sub base $\geq$ 200 mm
<ul> <li>6. wearing course 100 mm <ul> <li>IV SOIL REPLACEMENT</li> </ul> </li> <li>1. removal of old wearing course</li> <li>2. removal of old material ≥ 600 mm</li> <li>3. geotextile, filter cloth</li> <li>4. filter bed ≥ 300 mm</li> <li>5. base course 200 – 300 mm</li> <li>6. wearing course 100 mm</li> <li>V STRENGTHENING ROAD SHOULDERS</li> </ul> <li>several methods such as <ul> <li>soil replacement on road shoulders</li> <li>widening inner slopes</li> </ul> </li> <li>VI OTHER STRUCTURES</li> <li>several methods such as <ul> <li>stabilization</li> <li>frost insulation etc.</li> </ul> </li>	5.	base course 200 mm
IV SOIL REPLACEMENT         1. removal of old wearing course         2. removal of old material $\geq$ 600 mm         3. geotextile, filter cloth         4. filter bed $\geq$ 300 mm         5. base course 200 – 300 mm         6. wearing course 100 mm         V STRENGTHENING ROAD SHOULDERS         several methods such as         - soil replacement on road shoulders         - widening inner slopes         VI OTHER STRUCTURES         several methods such as         - stabilization         - frost insulation etc.	6.	wearing course 100 mm
<ol> <li>removal of old wearing course</li> <li>removal of old material ≥ 600 mm</li> <li>geotextile, filter cloth</li> <li>filter bed ≥ 300 mm</li> <li>base course 200 – 300 mm</li> <li>wearing course 100 mm</li> <li>v STRENGTHENING ROAD SHOULDERS</li> <li>soil replacement on road shoulders</li> <li>widening inner slopes</li> <li>VI OTHER STRUCTURES</li> <li>several methods such as</li> <li>stabilization</li> <li>frost insulation etc.</li> </ol>		IV SOIL REPLACEMENT
<ul> <li>2. removal of old material ≥ 600 mm</li> <li>3. geotextile, filter cloth</li> <li>4. filter bed ≥ 300 mm</li> <li>5. base course 200 – 300 mm</li> <li>6. wearing course 100 mm</li> <li>V STRENGTHENING ROAD SHOULDERS</li> <li>several methods such as <ul> <li>soil replacement on road shoulders</li> <li>widening inner slopes</li> </ul> </li> <li>VI OTHER STRUCTURES</li> <li>several methods such as <ul> <li>stabilization</li> <li>frost insulation etc.</li> </ul> </li> </ul>	1.	removal of old wearing course
<ul> <li>3. geotextile, filter cloth</li> <li>4. filter bed ≥ 300 mm</li> <li>5. base course 200 – 300 mm</li> <li>6. wearing course 100 mm</li> <li>V STRENGTHENING ROAD SHOULDERS</li> <li>several methods such as <ul> <li>soil replacement on road shoulders</li> <li>widening inner slopes</li> </ul> </li> <li>VI OTHER STRUCTURES</li> <li>several methods such as <ul> <li>stabilization</li> <li>frost insulation etc.</li> </ul> </li> </ul>	2.	removal of old material $\geq$ 600 mm
<ul> <li>4. filter bed ≥ 300 mm</li> <li>5. base course 200 – 300 mm</li> <li>6. wearing course 100 mm</li> <li>V STRENGTHENING ROAD SHOULDERS</li> <li>several methods such as <ul> <li>soil replacement on road shoulders</li> <li>widening inner slopes</li> </ul> </li> <li>VI OTHER STRUCTURES</li> <li>several methods such as <ul> <li>stabilization</li> <li>frost insulation etc.</li> </ul> </li> </ul>	3.	geotextile, filter cloth
5. base course 200 – 300 mm 6. wearing course 100 mm V STRENGTHENING ROAD SHOULDERS several methods such as - soil replacement on road shoulders - widening inner slopes VI OTHER STRUCTURES several methods such as - stabilization - frost insulation etc.	4.	filter bed $\geq$ 300 mm
	5.	base course 200 – 300 mm
V STRENGTHENING ROAD SHOULDERS         several methods such as         - soil replacement on road shoulders         - widening inner slopes         VI OTHER STRUCTURES         several methods such as         - stabilization         - frost insulation etc.	6.	wearing course 100 mm
several methods such as - soil replacement on road shoulders - widening inner slopes VI OTHER STRUCTURES several methods such as - stabilization - frost insulation etc.		V STRENGTHENING ROAD SHOULDERS
<ul> <li>soil replacement on road shoulders</li> <li>widening inner slopes</li> <li>VI OTHER STRUCTURES</li> <li>several methods such as</li> <li>stabilization</li> <li>frost insulation etc.</li> </ul>	severa	I methods such as
<ul> <li>widening inner slopes         VI OTHER STRUCTURES     </li> <li>several methods such as         <ul> <li>stabilization</li> <li>frost insulation etc.</li> </ul> </li> </ul>	-	soil replacement on road shoulders
VI OTHER STRUCTURES several methods such as - stabilization - frost insulation etc.	-	widening inner slopes
several methods such as <ul> <li>stabilization</li> <li>frost insulation etc.</li> </ul>		VI OTHER STRUCTURES
<ul> <li>stabilization</li> <li>frost insulation etc.</li> </ul>	severa	I methods such as
- frost insulation etc.	-	stabilization
	-	frost insulation etc.

The most suitable rehabilitation measure should be selected after the diagnosis of the problem. The suitability of rehabilitation methods for different damage classes are briefly described in the text that follow.

#### STRUCTURES I. "BASIC STRUCTURE" AND III. "RAISING ROAD ALIGNMENT"

This basic structure can be considered as a minimum structure for strengthening spring thaw weakened road sections on gravel roads. Basically the structure is suitable for repairing spring thaw damages in every damage class A-H of Table 2.2. In some circumstances heavier structures will be needed to ensure proper functionality of the road. Examples of this are:

- when the spring thaw problems appearing on site are medium or severe (subclasses II and III) and the improvement of bearing capacity using the basic structure is likely to be inadequate
- when a number of medium and/or severe spring thaw damages are located on a road section passing through a low lying valley or the damage is related to a low vertical alignment of the road:
  - moraine subgrade, flat and even area (Table 2.2, class B)
  - clay and/or silt subgrade, flat and even area (Table 2.2, class E)
  - clay and/or silt subgrade, wet and low lying valley (Table 2.2, class F)
  - peat subgrade, flat and even area or wet and low lying valley (Table 2.2, class G)

The thickness of the rehabilitation structure can be made using a dimensioning strategy such as that presented in ROADEX II project report "Permanent Deformation" (Dawson and Kolisoja 2005). In cases where the damages are related to the vertical alignment of the road the strengthening is best done by raising the grade line using a 500 - 600 mm thick new structure as shown in structure III. This thicker structure however can only be used where raising the road alignment and width is possible.

#### STRUCTURE II. "STEEL REINFORCEMENT"

In a case of a weak and/or compressible subgrade (Table 2.2, classes E, F and G) the risk of differential settlements should be carefully considered if thick rehabilitation structures are to be used. Differential settlements can be reduced by using structure II (see Table 5.1) where some of the aggregate thickness is reduced by a steel grid reinforcement (Figure 5.1). Reinforcement also works well against permanent deformation and it also reduces widening of the road by material flow during the spring thaw period.



Figure 5.1. Installation of steel reinforcement. (K. Niva)

Rehabilitation structures containing steel reinforcement are not recommended for use on damage sites located on sloping ground (Table 2.2, classes A, D and H). The uneven frost heave appearing on these sites may cause the reinforcement to rise up to the road surface. Steel reinforcement should also be avoided on sites where culverts, pipes or cables cross the road as they may need maintenance in future. In these sections steel reinforcement may hinder any future repair.

#### STRUCTURE IV. "SOIL REPLACEMENT"

When spring thaw damage is severe, with difficult differential frost heave, the only way to solve the problem in many cases is through soil replacement (Table 5.1, structure IV). Thick structural thickness soil replacement is, however, seldom an economical solution on low volume roads although it can be effective to replace soil

with frost resistant and water permeable material in those cases where bedrock is located close to the road surface (Table 2.2, class H.III). Soil replacement is not however the most appropriate rehabilitation measure in those locations where bedrock is blocking water. In this case, breaking out the bedrock should be considered or using a structure containing a frost insulation (Table 5.1, structure VI).

#### STRUCTURE V. "STRENGTHENING ROAD SHOULDERS"

In analysing spring thaw problem sections that have been repaired and failed, one factor that has repeatedly been observed as causing problems is where roads have been strengthened across the entire widened cross section. These widened shoulders have hardly any structure with the result that differential frost heave and heavy vehicles driving on the 'firm looking shoulder' cause failures. Basically, the road sections suffering weak bearing capacity on shoulders can include in any damage class presented in Table 2.2.

To avoid such situations the width of the cross-section should be narrowed when carrying out strengthening. Figure 5.2 presents a typical failing cross-section together with a cross-section illustrating how strengthening should be done. If it is not possible to narrow the road, a thicker road structure should be constructed on shoulders. Another alternative is to carry out soil replacement on the shoulders whereby the thin structures and subgrade are excavated and replaced by thicker road structures. In Sweden, soil replacement of road shoulders is probably the most common method for road shoulder strengthening.

Many different structures have been tested to try to identify effective solutions for strengthening road shoulders. Interesting new tests have been carried out using steel grids for reinforcing road shoulders. In these cases the grids have been installed longitudinally following the road shoulder to prevent shoulder deformation.



Figure 5.2. Typical cross-section that will fail and cross-section showing how strengthening should be done.

#### STRUCTURE VI. "OTHER STRUCTURES"

This category includes those strengthening methods which are not yet in common use for repairing spring thaw damages on gravel roads. Thus, structure VI consists of rehabilitation techniques that are only applied in special cases or which are still under development. This category includes wearing course coarsening as well as the structures containing frost insulation, geotextile reinforcement or by-products of industries.

Wearing course coarsening can be considered as a primary rehabilitation structure in cases where the surface thaw weakening appearing is related to a thick wearing course with a high content of fine material. In these cases new and coarser material is mixed with the old wearing course material in a designed proportion. This method

of wearing course coarsening can only be used for repairing damages due to surface thaw weakening.

Frost insulation can offer an effective rehabilitation structure on wet and side-sloping spring thaw damage sites. By using frost insulation, ground water can freely flow under the road and ice lenses are not therefore formed by frost blocking the water. In such a case frost insulation can also prevent the formation of uneven frost heave. (Saarenketo et al. 2002) Even though they are expensive, frost insulations can be considered as a competitive rehabilitation method in those cases where breaking out of bedrock is the alternative.

## 5.4 REHABILITATION STRUCTURES FOR PAVED ROADS

#### 5.4.1 General

The strengthening strategy of paved road with problems related to spring thaw weakening is as straightforward a process as that for gravel roads. All solutions for paved roads are normally more expensive than those of gravel roads and the thickness of the pavement has a great effect on the rehabilitation structure that can be used. For this reason paved roads in this report have been divided into two categories: roads where the overall thickness of the pavement and bituminous bound layer thickness is 20 - 100 mm in total and roads where the overall thickness of the bound layers is more than 100 mm. Old gravel roads with very thin surface dressing are considered to be special cases where the rehabilitation strategy should be selected case by case from structural options for gravel roads or paved roads.

#### 5.4.2 Roads with thin pavements - pavement thickness: 20 - 100 mm

General solutions and construction processes for strengthening paved roads with thin pavements suffering spring thaw weakening are presented in Table 5.2. It should however be kept in mind that all layers mentioned in the Table need to be compacted.

The total thickness of rehabilitation structures for paved roads should be determined in a case-specific fashion by using the strategy presented in the ROADEX II project report "Permanent Deformation" (Dawson and Kolisoja 2005) or for example by using the traditional dimensioning method such as Odemark. Treatment cards for rehabilitation methods for paved roads are not presented in this report but the repair methods for each structure, as well as their suitability for repairing different spring thaw damages, are described in following text.

# Table 5.2. The construction process for paved road rehabilitation structures. The process description does not list compaction that has to be always properly done.

#### I. NEW OVERLAY

1.the levelling or milling of the old pavement

2.new pavement or pavement remix

II. STEEL/GEOTEXTILE REINFORCEMENT

1.removal of old pavement / breaking old pavement / mixing old pavement with base course
2.removal of old poor quality base material 100 – 150 mm (if required)
3.shaping
4.base course 50 - 100 mm (coarse grading for ensuring interlock)
5.steel / geotextile reinforcement
6.base course 200 mm (can be partly bound)
7.new pavement

#### **III. RAISING ROAD ALIGNMENT**

removal of old pavement / breaking old pavement / mixing old pavement with base course
 homogenization 300 mm (if required)
 shaping

4.sub base  $\geq$  200 mm

5.base course 200 mm (can be partly bound)

6.new pavement

#### **IV. SOIL REPLACEMENT**

1.removal of old structures  $\geq$  600 mm (to subgrade level)

2.geotextile, filter cloth

3.filter course or subbase  $\geq$  300 mm

4.base course 200 - 300 mm (can be partly bound)

5.new pavement

#### V. STABILIZATION AND OTHER TREATMENT TECHNIQUES

1.stabilization of top 80 – 200 mm of pavement structure 2.new pavement

#### VI. HOMOGENIZATION

mixing old pavement with base course 50 – 200 mm
 road surface shaping (grader, adding new base course material)
 new pavement

#### VII. CONVERTING PAVED ROAD BACK TO GRAVEL ROAD

1. removal of old pavement / mixing the old pavement with base course

2. road surface shaping (grader, adding new base course material)

3. new wearing course

#### **VIII. OTHER STRUCTURES**

several methods such as

frost insulation

\_

quarrying etc.

#### STRUCTURE I. "NEW OVERLAY"

A new overlay is usually an adequate measure for strengthening roads in those sections where there are no major spring thaw weakening problems, there is low risk of further damage (no risk or low risk class, see Roadex II report "Monitoring, Communication and Information Systems & Tools for Focusing Actions" by Saarenketo 2005) and/or bearing capacity class is high. New overlay can normally be used in every class of road (A-H in Table 2.2) provided that there are no differential frost heave problems appearing. In these cases the old pavement is usually levelled or milled to the proper cross fall before the new pavement is laid.

#### STRUCTURE II. "STEEL REINFORCEMENT"

Steel grids have been used to prevent reflection cracking on paved roads for a number of years but recently field experience has shown that steel grid structures can also be used to prevent permanent deformation in spring thaw damage sites. The benefits of steel reinforcement seem to be greater on weaker subgrades and they are therefore recommended to be used on damage sites E-G in Table 2.2. When using steel grid structures either on paved or on gravel roads it is important to install the steel grids deep enough (optimum depth is 250 mm from the surface) and to ensure that the road structure does not contain any big boulders, which might push the grids up to the surface. Failures have appeared if steel grids have been installed too early in the spring when the subgrade has not completely thawed.

The first step in reinforcing a road with a relatively thin pavement using steel grids is to remove, break or mix the old pavement or surface dressing and homogenize the top part of the road structure. If the pavement surface level cannot be lifted, the top part of the pavement can be also removed during this phase. Before placing the steel grid the road should be shaped to proper cross falls using a grader and approximately 50 - 100 mm (0-35 mm, 0-55 mm) of coarse grained granular material laid to ensure interlock with the grid (Figure 5.3). The steel grid can then be installed and base course material laid on top and the structure compacted. The base course thickness is normally designed to be 200 - 400 mm depending on the severity of the spring thaw damage.



Figure 5.3. Coarse grained granular material should be used under the steel grid to ensure interlock. (T.Ruohomäki)

#### STRUCTURE III. "RAISING ROAD ALIGNMENT"

In those cases where spring thaw damage is related to the low vertical alignment of the road any strengthening is best done by raising the grade line. Raising the roadline can also be considered if the roadside drainage cannot be improved. This measure also improves road geometry and greatly reduces winter maintenance problems provided that the alignment is not raised so high that guardrails are needed.

This structure works best where problems can be classified into damage classes B and E-G (see Table 2.2). It can also be used on other classes although thicker structures may be required if the spring thaw damage appearing is severe. The total thickness of the new structures should be planned case-specific by dimensioning the structures. When raising the road alignment the cross section design is important to ensure that the new structures can be made in the existing road area and/or the inner road slopes do not become too steep.

#### STRUCTURE IV. "SOIL REPLACEMENT"

When spring thaw damage is severe and difficult differential frost heave is present in the same section the only way to solve the problem is to remove the frost-susceptible soil and road structures and build new road structures. This soil replacement structure is expensive due to the high amount of new road materials needed and its use on low volume roads has to be carefully evaluated. However it is, in most cases, the only solution to fix uneven bumps.

Soil replacement with coarse materials can work well where bedrock is present (class H.III) but not if the bedrock is seen to be blocking the ground water flow. In such cases, breaking out the bedrock in ditches should be also considered. In addition, a

structure containing a frost insulation layer may be another efficient choice (structure VII in Table 5.2).

#### STRUCTURE V. "STABILIZATION AND TREATMENT TECHNIQUES"

Stabilization and treatment techniques can be effective in strengthening a road against spring thaw weakening especially if a significant part of the permanent deformation takes place in the top part (0 - 250 mm) of the pavement structure. This method is a good choice if the base course has a high fines content and it is not possible to raise the road alignment. When using this structure it is always necessary to have some sampling and laboratory tests of base course to verify the problem and to define the right type and right proportioning of treatment agents. When designing stabilization, the most important thing, is to ensure that the stabilized material does not adsorb water where it is present. In wet conditions, such as damage classes B and E-G in Table 2.2, treatment agents with hydrophobic features can be used.

When done properly a 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 longitudinal cracking on stabilized roads. For this reason stabilization should be carefully studied if the damaged sites are located on sloping ground or on sites where bedrock is present (classes A, D and H in Table 2.2).

More information about stabilization and treatment techniques is given in ROADEX II project report "Material Treatment" (Kolisoja and Vuorimies 2005) and in ROADEX III project stabilization report.

#### STRUCTURE VI. "HOMOGENIZATION"

If there is limited funding available, homogenization of the top part of the pavement structure and new surface dressing or new cold mix pavement can be one of the cheapest techniques to rehabilitate paved roads suffering from spring thaw damage. Basically, homogenization can be used for all the damage classes A-H presented in Table 2.2 if the pavement is not thicker than 100 mm.

When using homogenization the existing pavement is first mixed with the base course (Figure 5.4). The mixing depth is normally from 50 - 200 mm, or deeper, but it should not be so deep that it brings large rocks or boulders closer to the surface. After homogenization the road surface is shaped to the optimum form, using a grader, and the homogenized material compacted and a new bituminous wearing course laid. This technique is especially good on roads with problems with deep ruts that are otherwise hard to fix. An additional benefit is that the road's cross-section can also be improved so that water will no longer lie on the pavement.



Figure 5.4. Current surface dressing is first mixed with the base course. (T.Ruohomäki)

The practice of adding new base course material, which also makes the homogenized base course thicker and improves its grading, has also been used on roads with major deformation problems during the spring thaw (subclasses II and III in Table 2.2). In this technique the existing pavement and the old base are first mixed after which the new base course is placed on top and another run made by the mixer prior to shaping, compaction and repaving of the structure. Other versions of the technique lay new base course material on top of the pavement before the homogenization process.

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

#### STRUCTURE VII. "CONVERTING PAVED ROAD BACK TO GRAVEL ROAD"

If the bituminous pavement in a road section is has had continuous severe problems with potholes, ravelling and rutting and the use of load 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 carried out on several roads, which have not had the 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. The road at the Ängesby Percostation site in Sweden in the ROADEX project is a good example of a road where the problems have decreased following the change back to gravel.

#### 5.4.3 Roads with thick pavements - pavement thickness > 100 mm

Normally low traffic volume roads in Northern Periphery area do not have thick pavement layers except in Scotland where the bitumen bound structure thickness is often more than 100 mm. In these roads, maintenance authorities generally follow the same principles outlined in section 5.4.2 above although as already stated the major winter seasonal problem to be overcome in Scotland is the daily freeze-thaw cycle, together with increasing moisture contents in subgrade soils. In these circumstances it will always be necessary to carry out a general drainage improvement to the road as part of the strengthening projects.

When selecting a rehabilitation method for a road with a thick bituminous overlay the nature of the problem has to be first outlined by classifying the pavement damage type.

If the road suffers from type 1 rutting due to poor quality base (see Dawson and Kolisoja 2005), and the pavement is 100 - 140 mm thick, the optimum rehabilitation solution could be to place a thicker overlay on the top of existing pavement. Results from the Roadex II project (Dawson and Kolisoja 2005) have shown that a 200 mm thick bound layer can reduce principal stresses to a level where no permanent deformation should take place. If the pavement is in very bad shape however a better option could be homogenization, the mixing of the existing pavement with the unbound base.

Where the pavement thickness is 100 mm and deep ruts and/or fast rutting can be considered to be related to a very weak subgrade (this can be verified from FWD data or GPR cross sections) the most economical option is to mill the bitumen bound layers away for reuse and, if possible, place a thicker unbound base course and a new pavement. A good option in these cases is a steel grid, especially if there is a risk of differential settlements due to a compressive subgrade. There have been good experiences with geogrids installed in bituminous layers in Scotland and this is a recommended option if the bituminous layers are greater than 200mm thick.

Sometimes pavement failures in thicker pavements can be related to severe disintegration of the bituminous layers due to poor drainage below the layers (stripping). This can give rise to high hydraulic pressures in the layers under the action of heavy traffic during thawing periods. In such cases the only solution is to improve the drainage, mill away the bituminous layers, place a water permeable aggregate layer on the prepared surface (macadam or open graded base) and finish with a new overlay.

If the pavement distress type is mainly longitudinal cracking with alligator cracking close to the road shoulder these problems can be related to differential frost heave or thaw settlement across the road cross section. If this is the case the reason can be due to poor drainage on sloping ground or an incorrectly widened road. The primary repair method in these cases is heavy improvement of the drainage. If cracking is close to wheel path, the pavement should be milled away and the unbound layers reinforced with steel grids before finishing with new bituminous layers as before.

# Chapter 6. Quality Assurance and Functionality Control of Rehabilitated Roads

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. For this reason it is recommended that greater focus should be made on quality assurance of construction procedures. In particular it is recommended that the contractor should be obliged to prove the quality of rehabilitation work. This should consist not only of the quality assurance of materials used but also the quality assurance of the on-site layer thicknesses, compaction and the correct location of the rehabilitation structures.

As a result of reducing budgets, rehabilitation measures for spring thaw weakened roads are usually only carried out on those parts of the road suffering spring thaw weakening. This means that precise location of the defects is needed so that those sections of road with a reasonable life expectancy can be left out of the project and investments only made in those sections that are in need of repair. For this kind of "precise rehabilitation" it is vital to have common positioning in surveys done before the rehabilitation and of the executed rehabilitation structures. If not, in the worst situation, strengthening measures may be applied on the wrong sections where defects have not been appearing.

In addition to the correct location of the strengthening structures it is also necessary to assure the thickness of the executed structures. This can be done by simply measuring the thickness from a trial pit excavated for that purpose. The layer thickness can also be verified by GPR measurements. Ground penetrating radar has been found to be an excellent tool for measuring the executed layer thickness by providing a continuous profile of road structures and, at the same time, ensuring the correct location of rehabilitation structures.

Compaction control on gravel road sections with spring thaw problems is difficult to ensure as the existing structures and subgrade soils are normally so weak. But in paved roads compaction control should always be done in order to avoid rutting. Density should be verified using the accepted methods in each country. Also combined use of GPR and FWD is recommended.

Figure 6.1 provides an excellent example of results obtained using GPR as a quality assurance method in Finnish gravel roads. It can be easily seen from the interpreted GPR data that the wearing course and base course have been laid thick enough but the location of the rehabilitation has been incorrect.



Figure 6.1. An incorrect location of the rehabilitation structure verified by GPR. (Pälli et al. 2005)

If new damages appear shortly after rehabilitation in repaired sites, they may be related to poor quality of materials used and special attention should be paid to this in quality control. National specifications for materials, their frost susceptible and grading, should be followed when executing strengthening measures. It is also good practice for the contractor to be asked to prove the quality of the materials used.

All deviations in locations, layer thicknesses and in material quality are important to identify so that the reasons for any new damages can be easily found. Contractors should always be required to repair section deficiences. Precise documentation of the rehabilitation measures carried out, their location and structures, are also a prerequisite for functionality control of the rehabilitated roads.

As mentioned in Chapter 3 the quality assurance of the rehabilitation process should be continued with systematic functionality control of the rehabilitated roads. This process should include analysis and rehabilitation of any new damage so that, as data grows from survey and follow-up, it will be possible to improve the predictability of spring thaw damage following the removal of load restrictions. Functionality control also provides valuable information regarding rehabilitation structures' service lives and their suitability for different damage classes.

## Chapter 7. References

Aho S. (2004). Sorateiden kelirikkokorjausten toimivuus ja elinkaarikustannukset. Diplomityö, Tampereen teknillinen yliopisto. Tampere. (English abstract)

Aho S., Saarenketo T., Berntsen G., Dawson A., Kolisoja P. and Munro R. (2005). Structural Innovations. ROADEX II report. <u>www.roadex.org</u>

Aho S., Saarenketo T. and Kolisoja P. (2005b). Kelirikkokorjausten suunnittelu ja rakentaminen. Vähäliikenteisten teiden taloudellinen ylläpito –tutkimusohjelma. Tiehallinnon selvityksiä 64/2005, Tiehallinto. Helsinki. (English abstract)

Berntsen G. and Saarenketo T. (2005). Drainage on Low Traffic Volume Roads. ROADEX II report. <u>www.roadex.org</u>

Dawson, A. and Kolisoja, P. 2005. Permanent deformation. ROADEX II report. <u>www.roadex.org</u>

Kolisoja P. and Vuorimies N. (2005). Material Treatment. ROADEX II report. <u>www.roadex.org</u>

Launonen P. ja Turunen P. (1995). Sään ja hydrologisten tekijöiden vaikutus kevätkelirikkoon. Tielaitoksen selvityksiä 20/1995. Kuopio. (in Finnish)

Niva, K. (2004). Finnish Road Administration, Lappi District. Photo.

Pälli A., Aho S. and Pesonen E. (2005). Ground Penetrating Radar as a Quality Assurance Method for Paven and Gravel Roads in Finland. 3<sup>rd</sup> International Workshop on Advanced Ground Penetrating Radar. May 2-3, 2005. Delft, The Netherlands.

Pennanen O. and Mäkelä O. (2003). Raakapuukuljetusten kelirkkohaittojen vähentäminen. Metsätehon Raportti 153, 19.8.2003. (in Finnish)

Roadex Project 1998-2001. Northern Periphery. CD-ROM

Ruohomäki, T (2004). Skanska. Photos.

Saarenketo, T. 2005. Monitoring, Communication and Information Systems & Tools for Focusing Actions. ROADEX II report. <u>www.roadex.org</u>

Saarenketo T. and Aho S. (2005). Managing Spring Thaw Weakening on Low Volume Roads. ROADEX II report. <u>www.roadex.org</u>

Saarenketo T. and Aho S. (2003). Kelirikkoteiden painorajoitusten yhtenäistäminen, Tiemestarikysely-tutkimuksen raportti. Roadscanners Oy. Rovaniemi, Tampere. (in Finnish).

Saarenketo T., Lähde A., Peltoniemi H. ja Rantanen T. (2002). Vaasan sorateiden korjaussuunnittelun kehittäminen. Tutkimusraportti. Roadscanners Oy. Rovaniemi. (in Finnish)

Saarenketo, T., 2001. GPR Based Road Analysis - a Cost Effective Tool for Road Rehabilitation Case History from Highway 21, Finland. In Proceeding of 20<sup>th</sup> ARRB Conference, Melbourne, Australia 19-21 March, 19 p.

Tielaitoksen selvityksiä 2/1993 (1993). Massanvaihto. Geotekniikan informaatiojulkaisuja. Tielaitos, Helsinki. (in Finnish)

White T.D. and Coree B.J. (1990). Threshold Pavement Thickness to Survive Spring Thaw. Third International Conference on Bearing Capacity of Roads and Airfields Proceedings. Volume 1. Trondheim, Norway. 3-5 July 1990.

# Appendix 1

# TREATMENT CARDS FOR GRAVEL ROAD REHABILITATION STRUCTURES

- I. Basic Structure, BS
- II. Steel Reinforcement, SRI
- III. Raising Road Alignment, RA
- IV. Soil Replacement, SRP

#### TREATMENT CARD

#### **GRAVEL ROAD REHABILITATION**

METHOD:

#### Structure I Basic Structure, BS



#### WORKING METHOD:

#### **Removal of Old Wearing Course, Subgrade Homogenization**

Rehabilitation is started with the removal of the existing wearing course material to the depth of 50 - 150 mm of road surface. Any old wearing course material should also be removed from the length of transition wedges. 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 material or on the road shoulders. After removing the old wearing course, the top 300 mm of the structure should be homogenized if needed. Homogenization is done in order to remove boulders and stones and create a homogenous platform for the new structure. Before placing the geotextile (filter cloth) the road should be shaped to the cross slope of 4% and compacted.

#### Filter Cloth, Base Course and Wearing Course

The geotextile is placed transverse to the road direction overlapping by at least 500 mm. The base course is laid over the geotextile and compacted. The base course thickness is normally 200 or 300 mm. The base course is shaped to the cross slope of 4% and 100 mm wearing course material is laid on it before being shaped again to the cross slope of 4%. If old wearing course material is to be re-used, a proportion design should be carried out with the new wearing course containing a maximum of 50% of old material. The transition wedges are reconstructed by shaping the base course material to a slope of 1:40, the wearing course is constructed to the full thickness of 100 mm. The geotextile (filter cloth) is not used in the transition structures.

#### TREATMENT CARD

#### **GRAVEL ROAD REHABILITATION**

METHOD:

Structure II Steel Reinforcement, SRI



#### WORKING METHOD:

#### **Removal of Old Material**

Rehabilitation is started with the removal of the existing wearing course material to the depth of 50 - 150 mm of road surface. Old wearing course material should also be removed from the length of transition wedges. 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 material or on the road shoulders. After removing the old wearing course, the remaining 100 - 150 mm of the old material should be removed if the ground appears variable. Later, this old material can be used on the road shoulders if needed. The excavation should be done at least 300 mm wider than the new road shoulder. Before placing the geotextile (filter cloth) the road should be shaped to the cross slope of 4 % and compacted.

#### **New Layers, Steel Reinforcement**

The geotextile is placed on the bottom of the excavation and 100 mm base course material is laid and compacted on it. The base course layer is shaped and compacted to the cross slope of 4% and the steel grid installed on it. The steel grid should extend into the inner slope by the length 'A', the steel grid's installation depth. The steel grid should be installed so that the transversal steel wire will be the lowest. Normally 200 mm of base course material is laid over the steel grid. The base course is shaped and compacted to the cross slope of 4% following which 100 mm of wearing course material is laid and compacted on top before being shaped to the cross slope of 4%. If old wearing course material is to be re-used, a proportion design should be carried out with the new wearing course containing a maximum of 50% of old material. The transition wedges are constructed by shaping the base course material to the slope of 1:40, the wearing course is constructed to the full thickness of 100 mm. The geotextile (filter cloth) is not used in the transition structures.

### TREATMENT CARD

#### **GRAVEL ROAD REHABILITATION**

METHOD:

#### Structure III Raising Road Alignement, RA



#### WORKING METHOD:

#### **Removal of Old Material, Subgrade Homogenization**

Rehabilitation is started with the removal of the existing wearing course material to the depth of 100 - 150 mm of road surface. Old wearing course material should also be removed from the length of transition wedges. 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 material or on the road shoulders. After removing the old wearing course, the top 300 mm of the structure should be homogenized if needed. The homogenization is done 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 the cross slope of 4 % and compacted.

#### **New Layers**

The geotextile is placed transversal to the road direction overlapping at least 500 mm. The thickness of 200 - 300 mm (structure IIIA) or > 300 mm (structure IIIB) of subbase material and the thickness of 200 mm base course material are compacted on the geotextile. The constructed layers are shaped and compacted to the cross slope of 4 % and 100 mm wearing course material is laid on them. Also the wearing course is shaped to the cross slope of 4 %. If old wearing course material is to be re-used, a proportion design should be carried out with the new wearing course containing a maximum of 50% of old material. The transition wedges are constructed by shaping the base course material to the slope of 1:40, the wearing course is constructed to the full thickness of 100 mm. The geotextile (filter cloth) is not used in the transition structures.

#### TREATMENT CARD **GRAVEL ROAD REHABILITATION** METHOD: Structure IV Soil Replacement, SRP Tien leveys: 6m (+/- 0,25m) Tsv Sisäluiskan Sivukaltevuus: 4 % (+/- 1%) kaltevuus 1:2...1:4 Ulkoluiskan Oja väh kaltevuus 0.5m väh. 1:2 1 2 3 4 N:o Paksuus Nimitys Materiaali Murske # 0-11mm TAI # 0-16mm 1 Kulutuskerros 100 mm Murske # 0-45mm TAI # 0-56mm 200 - 300 mm 2 Kantava kerros 3 Suodatinkerros Hk 300-600 TAI >600mm 4 Suodatinkangas lk N3

#### WORKING METHOD:

#### Removal of Old Material, Filter Cloth Installation and Transition Wedges 1:15

Rehabilitation is started with the removal of the existing material to the depth of 100 - 150 mm of road surface. Old wearing course material should also be removed from the length of transition wedges. 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 material or on the road shoulders. After removing the old wearing course, the old material is excavated to the depth of 600 - 900 mm (structure IVA) or >900 mm (structure IVB) from the road surface. The geotextile (filter cloth) is placed on the bottom of the excavation. The width of the excavation can be determined by using the Figure 1 (Tielaitoksen selvityksiä 2/1993). A part of the old material can be used on the road shoulders if needed.





(structure IVB) of filter base material and the thickness of 200 - 300 mm of base course material are laid and compacted. The base course is shaped and compacted to the cross slope of 4% and 100 mm wearing course material is laid on it before being shaped and compacted to the cross slope of 4%. If old wearing course material is to be re-used, a proportion design should be carried out with the new wearing course containing a maximum of 50% of old material.