



*Saara Aho, Timo Saarenketo, Geir Berntsen,
Andrew Dawson, Pauli Kolisoja, Ron Munro*

STRUCTURAL INNOVATIONS

*A summary of Roadex II project phase
II reports*



ROADEX II
NORTHERN PERIPHERY II



THIS PROJECT IS BEING PART-FINANCED
BY THE EUROPEAN UNION
European Regional Development Fund

Cover page photo: Kalervo Niva

STRUCTURAL INNOVATIONS

A SUMMARY OF ROADEX II PROJECT PHASE II REPORTS

April 2005

Saara Aho, Timo Saarenketo
ROADSCANNERS OY

Geir Berntsen
NORWEGIAN PUBLIC ROADS ADMINISTRATION

Andrew Dawson
UNIVERSITY OF NOTTINGHAM

Pauli Kolisoja
TAMPERE UNIVERSITY OF TECHNOLOGY

Ron Munro
THE HIGHLAND COUNCIL, SCOTLAND

PREFACE

This is a final report from the Phase III subproject 3_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 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 Tasks 2_1 “Permanent Deformation“, 2_2 “Material Treatment“, 2_3 “Spring Thaw Weakening“, 2_5 “Road Construction Over Peat” and 2_6 “Drainage” of the Roadex II project. The report will describe the typical road condition problems shared throughout the regions. It also presents the new structural innovations and best practise methods as a summary of the phase II subproject reports mentioned above.

The report consists of six different parts. The first part of the report, written by Timo Saarenketo and Saara Aho from Finland, gives a short review of problem analysis and diagnosis which should be done as a first measure when starting to improve the road network condition. The second part of the report, written by Geir Berntsen from Norway and Timo Saarenketo, classifies the typical drainage problems in the NP-area and gives different proposals for improving the presented problems. In the third part of the report the types of rutting caused by permanent deformation and a new tentative method description for strengthening design of low volume roads are published by Andrew Dawson from England and Pauli Kolisoja from Finland. In the fourth part of the report both traditional and non-traditional techniques are discussed by Pauli Kolisoja and Nuutti Vuorimies from Finland. In the fifth part Timo Saarenketo and Saara Aho present a new classification method for different spring thaw damage sites as well as structural solutions for repairing them. The sixth part of the report, written by Ron Munro from Scotland, presents the general aspects of structural solutions presently available to the practising road construction on peat.

Timo Saarenketo and Saara Aho have done the summarizing work of the subproject reports mentioned above. Virpi Halttu has edited the report, Kent Middleton has checked the language and Jaakko Saarenketo has given valuable help with graphics, all of the aforementioned people are from Roadscanners.

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.

Copyright ©2005 Roadex II Project

All rights reserved.

Roadex II Lead Partner: The Highland Council, Transport, Environmental & Community Service, HQ, Glenurquhart Road, Inverness IV3 5NX Scotland, Project co-ordinator: Mr. Richard Evans.

CONTENTS

1 INTRODUCTION	10
1.1 ROADEX II PROJECT	10
1.2 STRUCTURAL INNOVATIONS FOR LOW VOLUME ROADS	11
2 PROBLEM ANALYSIS AND DIAGNOSIS	12
REFERENCES	14
3 STRUCTURAL SOLUTIONS FOR DRAINAGE	15
3.1 GENERAL	15
3.2 MAINTENANCE RELATED DRAINAGE PROBLEMS	16
3.2.1 Problems caused by melting snow.....	16
3.2.2 Problems on existing drainage system.....	17
3.3 DESIGN RELATED PROBLEMS	19
3.3.1 General	19
3.3.2 Sloping ground	19
3.3.3 Drainage problems on “low ground”	20
3.3.4 Drainage problems on flat area.....	20
3.3.5 Drainage problems where the road is constructed in bedrock cuttings.....	21
3.4 OTHER PROBLEMS	21
3.4.1 Moisture trap	21
3.4.2 Stability problems in the outer slope	21
3.5 ECONOMIC EFFECTS OF DRAINAGE	22
3.6 SUMMARY AND RECOMMENDATIONS	24
REFERENCES	25
4 DESIGN AGAINST PERMANENT DEFORMATION	26
4.1 GENERAL	26
4.2 RUTTING	26
4.3 THE PRINCIPLE STUDY METHOD AND RESULTS	27
4.4 THE DESIGN STRATEGY TO PREVENT PERMANENT DEFORMATION	31

5.5 CONCLUDING REMARKS	35
REFERENCES	36
APPENDIX 1 – STRESS PLOTS	36
5 NEW SURVEY, LABORATORY AND TREATMENT TECHNIQUES	37
5.1 GENERAL	37
5.2 PERCOSTATION	37
5.3 TUBE SUCTION TEST, TS -TEST	38
5.4 DYNAMIC CONE PENETROMETER, DCP.....	38
5.5 MATERIAL TREATMENT TECHNIQUES ON LOW-VOLUME ROADS	39
5.5.1. General	39
5.5.2 Traditional treatment techniques	40
5.5.3 Non-traditional treatment techniques	40
5.5.4 Test methods.....	41
5.5.5 Conclusions of the test results	42
REFERENCES	43
6 STRUCTURAL SOLUTIONS FOR SPRING THAW WEAKENING	44
6.1 INTRODUCTION.....	44
6.2 SPRING THAW WEAKENING DAMAGE SITE CLASSIFICATION	44
6.2.1 Moraine subgrade	44
6.2.2 Peat	45
6.2.3 Bedrock	46
6.2.4 Silt and clay	46
6.2.5 Others	47
6.3 SPRING THAW DAMAGE MAINTENANCE TECHNIQUES	47
6.3.1 Drainage	47
6.3.2 Gravel road maintenance	48
6.3.3 Maintenance of paved roads	48
6.4 SPRING THAW DAMAGE STRENGTHENING TECHNIQUES	49
6.4.1 Converting a paved road back to a gravel road.....	49
6.4.2 Basic structural options for repairing spring thaw damage on gravel roads	49
6.4.4 Homogenisation.....	53
6.4.5 Stabilization and treatment techniques	53

6.4.6 Reinforcement	54
6.5 SUMMARY AND CONCLUSIONS.....	55
REFERENCES	56
7 STRUCTURAL SOLUTIONS FOR ROAD CONSTRUCTION OVER PEAT	57
7.1 GENERAL	57
7.2 ENGINEERING CONSIDERATIONS	57
7.3 TYPES OF CONSTRUCTION ON PEAT	58
7.3.1 General	58
7.3.2 Avoidance.....	58
7.3.3 Peat excavation.....	59
7.3.3 Peat replacement.....	59
7.3.4 Peat displacement	59
7.3.5 Peat left in place	61
7.4 DISCUSSION AND SUMMARY	68
REFERENCES	69
8 SUMMARY	70
ROAD EX PUBLICATIONS	72

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 3_3 “Structural Innovations” was to present and summarize the key findings of the Roadex project phase II results. The report follows the Roadex II Project phase III theme of “innovation and testing” by summarizing the new structural innovations and best practise methods which are specially customized for dealing with the typical road condition problems that can arise in the rural public, private and forest roads in the Northern Periphery. The report describes the procedures that should be followed when trying to improve the condition of the low volume road network.

The first step when planning to improve the condition of the road network is to collect reliable information describing the road condition and causes of failures. The second step is to identify the problem road sections by using the collected data. The integrated survey analysis should also be used in the third step which is the diagnosis of problems. The report presents the basic principles of the road analysis techniques as well as new road testing and laboratory testing techniques, which have proven to work well in these investigations. These techniques include, for example, the use of Dynamic Cone Penetrometer (DCP), Ground Penetrating Radar (GPR), Falling Weight Deflectometer (FWD), GPS and digital videos. However, the importance of taking good quality laboratory samples and performing special material tests is also emphasized.

The second part of the report classifies the typical drainage problems in the NP-area and gives different proposals for improving the problems. Results of life cycle cost analyses (LCA) done in the Roadex project clearly demonstrate the great economic benefits of the good working drainage system. The third part classifies the types of rutting caused by permanent deformation and also reports ways to evaluate the likelihood of excessive permanent deformation. Report also publishes a new tentative method description for strengthening design of low volume public, private and forest road pavement structures. In the fourth part of the report both traditional and non-traditional treatment techniques are discussed. The test results conclude that different types of treatment agents should be used for different types of unbound aggregates and soil materials. The fifth part of the report focuses on structural solutions that have been found to work well against spring thaw problems. As basic information for selecting optimum repair solution a new classification for spring thaw weakening sites is presented. Based on this classification several structural solutions are described and the construction techniques as well as their life cycle costs are also presented. A review of the engineering properties of peat as well as the general aspects of structural solutions presently available to the practising road construction on peat are presented in the sixth part of the report.

Rural roads in the Northern Periphery area do not have, in most cases, only a single reason for their problems and it is also important to understand the combined effect of several different factors, including loading by heavy vehicles. In order to produce sustainable and cost effective repair solutions, each problem section requires good survey data, correct diagnosis and careful design before the selection and execution of the rehabilitation structure. Also the needs of the road users should always be kept in mind when selecting the measures, locations and timing of road condition improvements.

KEY WORDS: Roadex, structural innovations, drainage, permanent deformation, Percostation, Tube Suction –test, DCP test, material treatment, spring thaw weakening, peat.



1 Introduction

1.1 Roadex II project

The ROADDEX 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 (Figure 1). One of the major goals of the Project is to strengthen and reinforce the first ROADDEX technical exchange and co-operation that was established in the Northern Periphery during the years from 1998 to 2001.

Within this overall strategy the specific objective of ROADDEX 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.



Figure 1. Northern Periphery Area and Roadex II partners.

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 throughout all of 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 Structural innovations for low volume roads

As mentioned earlier, the Roadex II project phase II consists of several subprojects, which are related to the technical details of the road condition problems shared throughout the regions. This report included in the Roadex II project phase III in which the new structural innovations and best practise methods are presented as a summary of the following phase II subproject reports:

- Drainage on low traffic volume roads
- Permanent Deformation
- Material Treatment
- Managing spring thaw weakening on low volume roads
- Dealing with bearing capacity problems on low volume roads constructed on peat

This report aims to summarize and to present the key findings of phase II subproject reports. More detailed information is available in the subproject reports mentioned above.



2 Problem analysis and diagnosis

The major problem in most of the projects to strengthen low volume roads and/or improving their condition has been that the structural solutions have mainly been selected on a hit-and-miss basis and thus are based only on the experience of the local engineers. This has led, in many cases, to the use of a single structural solution for every problem encountered in the road – which, in some cases, will work and in others not. The reason for this has been that the history of the road network in NP areas is relatively short and resources have mainly been focused on constructing new road structures. As such, proper data collection and design has only been done if the road has been totally reconstructed and road alignment has been improved. Another problem is that the history of the road problems and especially their locations is not well documented. A good rehabilitation structure in the wrong place is a waste of limited resources but constructing structures that are too weak is also not beneficial in the long term. The limited knowledge of the life cycle costs of different structural solutions has also resulted, many times, in the optimum strengthening measure being ignored. That is the reason why a systematic step-by-step analytical approach is needed whereby the most sustainable solution will be selected for each problem road section.

Prior to being able to select an optimum structural solution for a road section it is necessary to collect enough reliable information about the existing road, its condition and structures and about 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 technique for rutting and roughness information, visual evaluation data regarding drainage condition and taking samples from the road structures and subgrade soil should be utilized. Visual distress evaluation data and other reference information, such as video images from the road, would also be useful. All of this data should also be collected in a way that their precise location on the road is known. More details regarding these techniques are given in other Roadex II reports, such as “Dealing with Bearing Capacity Problems on Low Volume Roads Constructed on Peat” (written by Munro 2004), “Monitoring, Communication and Information Systems & Tools for Focusing Actions” (written by Saarenketo 2005) and “Managing Spring Thaw Weakening on Low Volume Roads” (written by Saarenketo & Aho 2005).

After the data has been collected the road should be divided into homogenous sections based on the integrated analysis of this data and the following key elements affecting the performance of the lifetime (see Saarenketo 2001):

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

Based on the results of this analysis, problem sections and also sections with potential to become problematic in the near future should be identified for further analysis. These sections require a more detailed problem diagnosis in order to classify the type of structural defects and their causes. Once this diagnosis has been done the road survey data and other information should be used to propose the most suitable rehabilitation measure or measures for each particular type of road defect in each road section (Saarenketo 2001).

A step-by-step procedure for analysing the condition that necessitate the rehabilitation measures is presented below. This procedure also follow as the general structure of this report.

A. Drainage condition

Drainage condition should not only be analysed in the problem sections but throughout the road length. That is because drainage improvement will prevent or at least postpone the development of other road defects. Drainage condition should be analysed through a visual evaluation but GPR data can also provide some information about the drainage condition.

B. Overall pavement condition

On paved roads the overall pavement condition assessment includes the evaluation of whether the problems are related to the pavement mixture, debonding, stripping or other types of pavement defects. Pavement condition can also be evaluated visually, but drill cores, GPR and FWD techniques as well as profilometers can also be used if there are enough resources available.

C. Assessment of the condition of the unbound road structures

The quality of unbound road structures should be evaluated from GPR data, FWD data and by sampling. A DCP can also be used if the maximum grain size of the aggregates is not too big. The mode of the rutting should be also classified in this phase (see chapter 4.2). Proper laboratory analysis of the material quality and moisture susceptibility should always be done if the problems are thought to be related to unbound materials.

D. Subgrade damage related to frost fatigue

Identification of road problems related to frost action and spring thaw weakening always require a combined analysis of several factors. GPR data provides good information and on paved roads also IRI data (and some times rutting data) from a profilometer is very valuable. Frost heave measurements always verify this type of damage but they are quite expensive to make and winter conditions can vary a great deal. On gravel roads spring thaw damage observations are the most valuable source data.

E. Subgrade damage related to very weak subgrade (silt, peat)

FWD data is the best technique to evaluate reliably if the road problems are related to weak subgrade. Especially GPR cross sections provide valuable information concerning the rutting mode and the thickness of the weak subgrade.

F. Local damage of the surveyed road, such as settlements, culverts etc.

Classified "local damages" covers all of the classes that are related to individual objects on the road or, for instance, a road structure that has not been built / designed properly. The scope and scale of these problems should be always analysed case-by-case.

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). Once a detailed problem analysis has been completed, the results also allow the possibility of leaving road sections with a reasonable life expectancy out of the project and investing in the measures in those sections that are in need of repair.

References

Munro, R., 2004. Dealing with Bearing Capacity Problems on Low Volume Roads Constructed on Peat. Roadex II report. www.roadex.org

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

Saarenketo, T., 2005. Monitoring, Communication and Information Systems & Tools for Focusing Actions. Roadex II report. www.roadex.org

Saarenketo, T. & Aho S., 2005. Managing Spring Thaw Weakening on Low Volume Roads. Roadex II report. www.roadex.org



3 Structural solutions for drainage

3.1 General

Funding for road condition management has been decreasing in all of the countries participating in the Roadex project for several years and as a result basic ditch maintenance tasks as well as tasks related to the drainage system in general are neglected since they are low on the list of priorities. Instead of drainage maintenance the prioritised tasks have been those that are more important to the road user in the short term i.e. repaving and snow removal.

It is a well-known fact that increased moisture content reduces the bearing capacity of a soil, which will increase the rate of deterioration and shorten the lifetime of the roads. In such cases, roads will need rehabilitation more often than a well drained road structure. The prediction models used, demonstrate clearly that maintaining and improving the drainage system is perhaps the most cost effective task to perform on roads where inadequate drainage is the main cause of deterioration. Improving the drainage system will lower the LCC due to increasing the lifetime of the road. The economic effects of drainage are discussed more in chapter 3.5.

Typical drainage problems in the NP-area were mapped using a questionnaire. Even though the ground conditions, landscape and climate vary a lot throughout the NP-area, the drainage problems are basically the same. The exception being Scotland where there are some special problems related to the use of grass verges. The problems are grouped in three main categories as shown in Figure 2. The drainage problem classification and the practices recommended for improving the problems are presented in chapters 3.2 – 3.4.

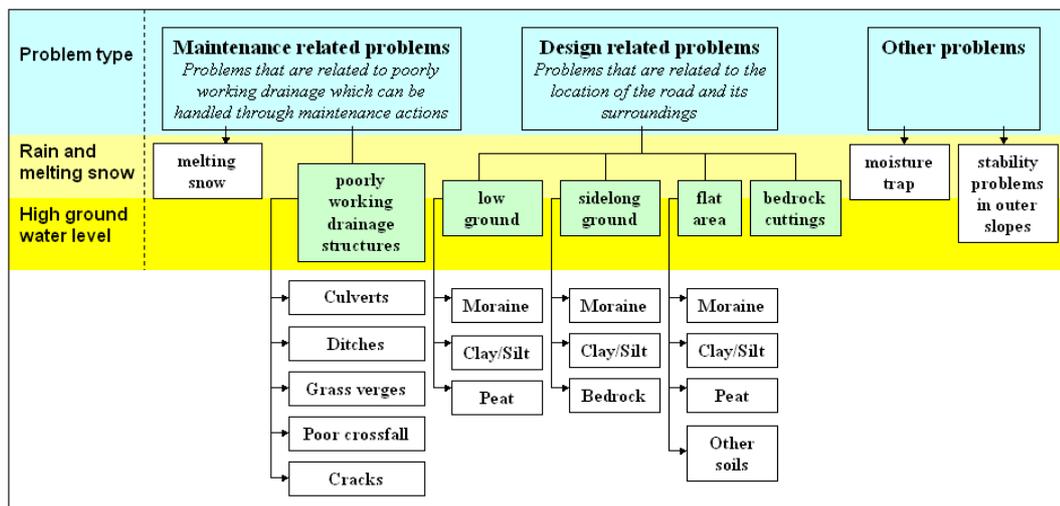


Figure 2. Category of drainage problems.

More detailed descriptions of the drainage problems and life cycle cost analysis are presented in Roadex II project phase II report “Drainage on Low Traffic Volume Roads” written by Berntsen & Saarenketo (2005). The original report also includes a literature review on moisture content in the road structure and the relationship between moisture content and the characteristics of unbound granular materials and subsoil.

3.2 Maintenance related drainage problems

3.2.1 Problems caused by melting snow

During thawing periods there can be a lot of water from melted snow and possibly even from spring rains on the road surface and in the ditches. In areas that have a low annual average temperature, thawing starts mainly from the top and proceeds downwards and a small amount of the thawing starts from the bottom of the frozen soil and proceeds upwards.

The frozen soils are almost impermeable in comparison to non-frozen soils. The melt water and rainwater do not drain because the ditches are filled with snow and, as such, are not functioning. Excess water from the ice lenses, in that case, has only one path through which to drain that being upwards through the road structure, which together with the surface water will cause an excess pore water pressure. This together with the high moisture content will reduce bearing capacity during these periods. Drainage problems during spring thaw are described in Figure 3.

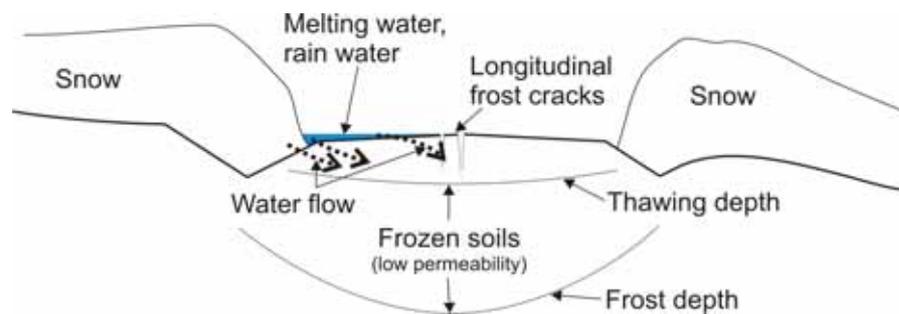


Figure 3. Drainage problems during spring thaw.

Improvement techniques - suggestions

- Snow can be cleared from the ditches during the thawing periods to remove the surface water
- Use of deep drainage
- Frost insulation (expensive)
- Raise the carriageway and make wider and deeper ditches
- Use materials in the road structure that are not susceptible to water or frost
- When designing a road structure, the bearing capacity of the subgrade soils during the critical spring thaw period must be considered.

3.2.2 Problems on existing drainage system

Culverts

If the stream velocity is lower in the culvert than upstream sand and gravel will be deposited in the culvert. As such, an important maintenance operation is to clear the culvert when the amount of deposited material has reached a predetermined level. If this is neglected the culvert will not have sufficient capacity to drain the water and the water will flow across the road surface and into the road structure. This is a traffic safety problem and may also cause erosion with the possible consequence of the road being washed away. The inlet of the culverts may also be clogged by branches, mud, gravel, rubbish and other kinds of things. The consequence is the same as described above.

Shallow placement, low flow velocity of the water and limited drainage area make the culvert susceptible to frost. Ice can clog the culverts and this problem can be severe during the spring thaw when the snow melts and the need for working culvert is urgent (Figure 4).



Figure 4. Ice clogging a transverse culvert.

Improvement techniques - suggestions

- Inspect and clear both the inlet and the culvert when necessary
- Steam the culvert to remove the ice blockage
- Solar panel and heater cable
- For difficult problems there may be a need to replace the drainage system with deep drainage and an outlet basin with a sand trap
- Reconstruct the culvert/inlet

Due to frost heaves, settlements or faulty construction, the culverts crack and deteriorate. The consequence is that water will flow uncontrolled and may cause erosion and raise the ground water table. When extreme water flows occur, the result may be that the road structure will be washed away and the road must be consequently closed.

Improvement techniques - suggestions

- Exchange the culvert and make a sufficient bed. Frost free foundation.
- Reline the culvert using a PEH pipe inside the old culvert and inject concrete between the two pipes

Ditches

Mud and vegetation will after some years fill up the bottom of the ditch and the drainage capacity will be reduced (see Figure 5). The consequence is that the ground water table rises in the road structure and the bearing capacity is reduced. In areas where the subsoil is fine graded, the need for ditch clearing is greater than it would be normally because these soils are easily eroded. Fine graded soils also have low bearing capacity at high moisture content and it is therefore necessary to have a good working drainage system.



Figure 5. Clogging of ditches in silt area.

Improvement techniques - suggestions

- Clearing the ditches often enough
- Erosion protection. Exchange the material in outer slope of the ditch using coarse aggregate and geotextile
- “Piping the ditch” (subsurface drain)
- Ditch trenches filled with coarse material

Grass verges

High grass verges are a problem mainly in Scotland on the older narrow road network but the other NP areas also have a similar kind of problem when the turf on the road shoulder edge grows higher than the asphalt surface. The surface water is then forced to drain through the pavement structure instead of draining to normal ditches. This results in reduced bearing capacity and deformations.

Improvement techniques - suggestions

- Remove the verges and turfs, make ditches to drain surface water and pavement structure
- Deep drainage (subdrain)
- Edge drainage

Poor cross fall

How fast water drains from the road surface is, along with other factors, dependent on the effectiveness of the cross fall. This depends on the transverse cross fall and the slope of the road. In Norway in order for cross fall to be considered effective it must be at least 1 %.

Ruts and an uneven road surface prevent the surface water from draining. Surface water will infiltrate the road structure, the amount of which depends on cracks, potholes and the permeability of the pavement.

Water on the road surface is mainly a traffic safety problem. A wet surface reduces friction which leads to longer braking distance. Surface water will also freeze at night during those times of the frost nights and temperatures above freezing during the day. The roads become very slippery if this happens and the change in friction may come as a surprise to those who are driving. The correct cross fall can be obtained through rehabilitation or resurfacing of the road.

Cracks and pothole

The low traffic volumes roads in Sweden, Finland and Norway have a very thin asphalt surface layer and crushed gravel is often used in the base course. The stiffness of the gravel course is low compared to other base materials and this can cause large horizontal stresses in the asphalt surface layer. If the bitumen is stiff this will result in alligator and longitudinal cracking. In addition, cracking caused by frost heave, weak edges and heavy wheel loads is common.

The surface is often uneven on these roads and water is concentrated in ruts and other recesses. If the surface is cracked, the water will penetrate into the gravel course and reduce the bearing capacity of the material. This will accelerate the deterioration of the road.

To handle this problem, flexible materials must be used in the surface layer and, as such, soft bitumen is recommended. It's also important to seal the surface so that the water will flow into the ditches and not into the road structure.

3.3 Design related problems

3.3.1 General

Even if the drainage system is constructed according to the guidelines, the system can still be insufficient. The guidelines cannot cover all of the possibilities, but if it is evident that the problems are caused by moisture in the road structure there is a need to improve the existing drainage system.

3.3.2 Sloping ground

In the greater part of the NP-area the roads are constructed on sloping ground where one half of the road is situated in a cutting and the other half of the road is situated on an embankment as shown in Figure 6. This problem is normally found in areas with moraine and sand/silt materials. Where the subgrade soil is clay or peat, the terrain is normally flat.

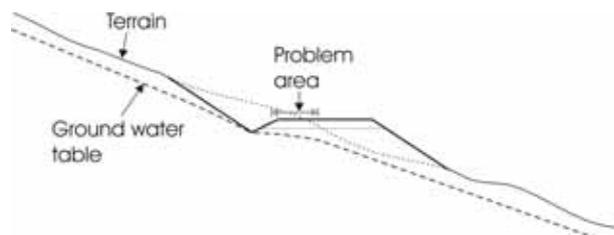


Figure 6. Drainage problem on sidelong ground.

In these cases the ground water table will normally be nearer to the road surface (and to the wheel load) on the road cut side. The moisture content is a function of the distance from the ground water table and thus the rut deformation in the upper wheel track is higher on sloping ground. The consequence is that the road cut side triggers the need for rehabilitation many years earlier than the well-drained embankment side. The lifetime ratio (drained lane / undrained lane) may be more than 2.

On sloping ground the ground water will flow under the road. If there is bedrock or impermeable materials near the road area, these objects may block or concentrate the ground water in places where the potential for developing frost heaves, spring thaw softening and reduced bearing capacity due to high moisture content is high.

Improvement techniques - suggestions

- Increase the road structure (soil replacement) on the road cut side or raise the grade line of the carriageway
- Use a subdrain to lower the ground water table on the road cut side
- Edge drainage
- Remove bedrock/impermeable materials that block the ground water flow
- Frost insulation (expensive)
- The use of additional culverts in places the water is being blocked

3.3.3 Drainage problems on “low ground”

In areas of low ground where the natural drainage system for surface water is not present then the water has to infiltrate the subgrade soil. When the ground is frozen or after period of heavy rainfall or snow melt, the water will have accumulated on the surface and will cause problems for the road as shown in the picture in Figure 7. In addition to creating difficulties for traffic, the raised ground water table will increase the deterioration of the road. On gravel roads this can soften the road structure and the road surface to the extent that the road becomes impassable.

Improvement techniques - suggestions

- Moraine subgrade
- It is possible to make infiltration wells or infiltration ditches
 - Raise the grade line of the carriageway (also helps winter maintenance)
- Clay, silt or peat subgrade
- Raise the grade line of the carriageway (also helps winter maintenance)
 - Infiltration is not possible.



Figure 7. Drainage problem on “low ground”.

3.3.4 Drainage problems on flat area

When a road crosses a flat area there will be problems similar to those located on low-lying ground. WHEN there is a long distance to the natural drainage system and, as such, it is difficult to get rid of the water. This problem is most apparent during the spring thaw when the ground is still frozen and there is a lot of water from melted snow and rainwater. Also during periods of heavy rainfalls the subsoil may have problems draining the surface water. The extent of the problem depends on the amount of water and the permeability of the subsoil. In any case, the ground water table will raise and the consequences are described in the previous section.

Improvement techniques - suggestions

- Moraine subgrade
- Raise the grade line of the carriageway
 - Replace road materials with materials not susceptible to water and frost
 - Infiltration wells or ditch
 - Long ditches (long outlet ditches) or deep drainage
- Clay, silt or peat subgrade
- Infiltration is not possible
 - Raise the grade line of the carriageway – (watch for possible settlements)
 - Long ditches (long outlet ditches) (surface or subdrain)

3.3.5 Drainage problems where the road is constructed in bedrock cuttings

Water will not drain from the road structure, which leads to a reduced bearing capacity. During the frost season, ice lenses form on top of the bedrock, which causes uneven bumps in the road surface. Depressions in the bedrock surface collect water and if there are frost susceptible materials in the road structure segregation ice will form.

Bedrock may also block the water under the road and to road structures from roadside and bedrock/boulder dams the water flow on a long distance.

Improvement techniques - suggestions

- Blast the bedrock to a depth of 1-2 m below foundation. This will create cracks in the bedrock and the water will be able to drain from the road structure
- Ditches/deep drainage that prevent the water from entering the road structure
- Frost insulation
- Remove basins in the bedrock that are collecting water.

3.4 Other problems

3.4.1 Moisture trap

In a number of roads that were reinforced during the seventies and the eighties, the normal method was to put gravel layers directly on top of the old bound surface, to form a sandwich construction. Water that penetrates the asphalt surface, unpaved road shoulder and from the ditches (during the snow melt periods) will be trapped between these two bound layers. The moisture content will increase more than it would for a normal road structure and will be moist for a longer time due to the lack of drainage possibilities. If the moisture content is close to the saturation level a dynamic load will cause high hydraulic pressure and this breaks the pavement above.

Improvement techniques - suggestions

- Mill through the structure to crush the lower bound layers.
- Add foamed or emulsified bitumen when milling to stabilise the materials

3.4.2 Stability problems in the outer slope

The materials from the damaged slopes flow into the ditches and block the water flow and cause the ground water level to rise. The problem is worst where there is fine graded sand and silt, and the ground water flow is large.

Improvement techniques - suggestions

- Surface drains
- Back drain ditch above the upper shoulder of the outer slope to take control of the surface water and lower the ground water table
- Vegetation
- Cover the slope surface with coarse graded gravel or macadam. Geotextile between the subsoil and the coarse material

3.5 Economic effects of drainage

Predictions models have been used to demonstrate that the lifetime of the pavement structure (calculated as number of standard axles) will increase considerably when drainage is improved. The Swedish design system has, among others, been used to calculate some examples the results of which indicate that by improving the drainage alone the lifetime will increase by a factor of 2.2-2.6 times.

All other prediction models produce a similar or even greater effect. Both field observations and prediction models indicate that improving the drainage will increase the pavement lifetime. On the basis of the observations and models the problem areas were categorized into groups where the conditions are similar and the effects of improvements are the same. Table 1 presents the estimated increase in lifetime the drainage is improved.

Table 1. Changes in lifetime when the drainage system is improved.

Drainage condition	Drainage classes 1)	Factor - change in lifetime by improving the drainage system
<p><i>Group 1</i> Drainage system does not work at all (or drainage system does not exist). Water susceptible soil in road structure and subgrade. Very high ground water table. Low ground and rocks blocking the ground water flow.</p>	>3	> 2,5
<p><i>Group 2</i> Drainage system does not work at all and the soil in the road structure and subgrade are less water susceptible than in group 1. Drainage system is functioning poorly due to a lack of maintenance (ditches and culverts not cleared) and water susceptible soil in road structure and subgrade.</p>	3	2-2,5
<p><i>Group 3</i> Drainage system is functioning poorly due to a lack of maintenance. (Ditches and culverts not cleared.) The soil in the road structure and subgrade are less water susceptible.</p>	2	1,5-2
<p><i>Group 4</i> Drainage system is working unsatisfactorily due to a lack of maintenance or the maintenance guidelines are insufficient.</p>	1-2	1-1,5

1) Comparison to the drainage classes in the Swedish design guide

Knowing the cost of drainage maintenance and improvements is essential in order to be able to calculate the effect on life cycle costs. The costs will vary between the countries in the NP-area and also within each country.

Normally the cost of maintaining the drainage system is much less than resurfacing and in Norway, for instance, resurfacing a low traffic volume road will cost 8-10 times more than clearing the ditches and culverts (Ditch clearing costs 10-12 % of the repaving costs.) (New pavement: 32-37 €/meter. Ditch clearing: 3.7-4.5 €/meter). In Finland, where the LC analysis was also done, the prices were lower but the ratio between ditch cleaning and new pavement was roughly the same.

A ditch may not work even though it has been shaped according to the design guidelines. In such cases the drainage has to be improved by increasing the depth of the ditch or by using deep drainage. These improvements are more expensive and the costs depend on the nature of the problem. Normally, drainage improvements should be done 1 -2 years before repaving. The cost of installing deep drainage ranges from 30 -50% of the cost of repaving depending on the type of subgrade soil.

A comparison between the costs of repaving of 5 or 6 meter wide road and costs of ditch clearing was done. Normally there are only short parts of a long section that have deteriorated due to inadequate drainage, but these short parts are the reason why the whole section has to be repaved. Looking at an entire section the relative costs will be still reduced and making drainage improvements will thus even more cost effective.

An interesting question is how often drainage improvement measures can be taken while still keeping the life cycle costs profitable. As an example, LCA calculations were made using a drainage improvement cost of 4.100 €/km and a pavement replacement cost 35.000 €/km (ratio 0.117). The results of this analysis can be seen in Figure 8. The figure shows that by improving/maintaining the drainage it is possible to double the lifetime (from 10 to 20 years) and that drainage maintenance can be done every second year and this will still be profitable even though the discount rate is as high as 8 % (used in Norway). If the increase in lifetime is only by 50 % (from 10 to 15 years) and the discount rate is only 4 % (used in Finland), drainage maintenance can still be done every third year. Normally there is no need for doing drainage maintenance more often than this. This example calculation also did not take into account increases in other maintenance costs due poorly working drainage and the benefits of keeping drainage in good condition should be calculated for longer than one pavement life cycle because frost fatigue, due to high moisture content, will affect the long term performance of the road structures.

The calculations also showed that it is always worth evaluating the use of more expensive drainage improvement solutions than ditch cleaning alone. For instance, if pavement lifetime can be doubled and the discount rate is 4 % drainage improvement can cost 8400 €/km and it can be still renewed every 5 years and the life cycle costs would still be less than without drainage renovation.

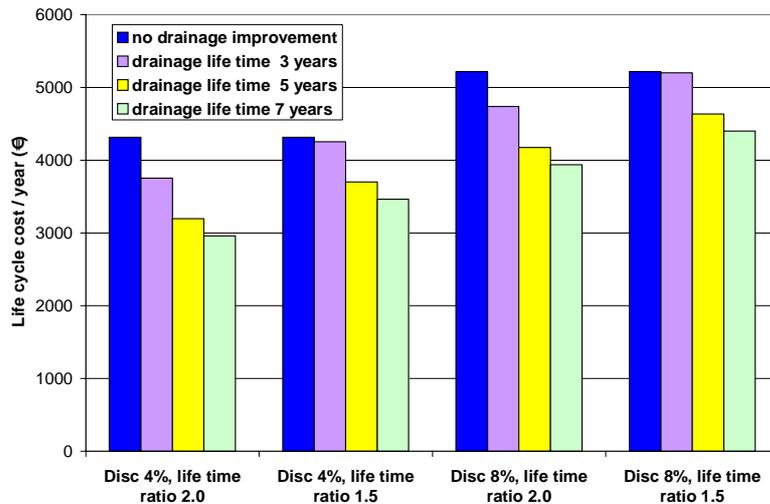


Figure 8. Example of life cycle cost analysis results showing the benefits of drainage improvements. In these costs, pavement rehabilitation costs have been calculated at 35.000 €/km and drainage improvement costs 4100 €/km. Results are presented using two lifetime ratios of 2.0 (10 to 20 years) and 1.5 (10 to 15 years and using to discount rates (4 % and 8%).

The conclusion is that maintaining the drainage system is cost effective and must be prioritised among other maintenance activities. The first step in strengthening a road should be to make the drainage system work properly and this should be done 1-2 years before paving. The effect of drainage on the road life cycle costs is discussed in more detail in the Roadex II phase II report “Drainage on Low Traffic Volume Roads”, written by Berntsen & Saarenketo (2005).

3.6 Summary and recommendations

This chapter describes the typical drainage problems in the NP-area and makes suggestions on how to solve the problems. The original report by Berntsen & Saarenketo (2005) describes, in more detail, the effect that inadequate drainage has on the deterioration of a road, field observations on deterioration due to a lack of drainage and different models that can be used to predict the level of the deterioration. The LCA for drainage improvements was also discussed in the report.

The original report has several parts. The first part is a literature review concerning moisture content in road structures and subgrade soils and the effect moisture has on the characteristics of unbound road construction material. All of the research on the subject clearly shows that the bearing capacity of unbound granular materials (E-modulus, deformation properties) is affected by changes in the moisture content. For coarse graded and open graded soils this effect is less significant. But with dense graded materials and materials with a high content of fines the characteristics can change considerably.

The second part of the original report classifies the typical drainage problems in the NP-area and also describes how to recognize these problems. The biggest problems are in road sections located on sloping hills. The publication also gives different proposals for improving the problems which have also been presented in this report. A summary of the classification method and a proposal for improvement methods and structures is presented as an appendix in the original report “Drainage on Low Traffic Volume Roads”, written by Berntsen & Saarenketo (2005).

The third part of the original report presents modeling and theoretical calculations concerning the effect of drainage on the pavement lifetime. This research was based on the Swedish design guide and the AASTHO design guide. The results of these calculations showed that functioning drainage will increase the pavement lifetime depending on models and structures used by a factor of 1.7 - 2.6.

In the fourth part of the original report, theoretical calculations were verified through field observations in Norway and Finland. The observations from individual test cases gave a lifetime ratio of 1.6 – 2.2 for road lanes located on poorly drained and well drained sites. In network level investigations of 184 km of road in Norway, 19.5 % of the road network had a pavement lifetime ratio greater than 1.5. When normally trigger values for rehabilitation measures or repaving are based on the fact that 15 – 20 % of rutting values are higher than the trigger values these calculations show that poorly working drainage is the key parameter governing the timing for a new pavement.

In the fifth part of the original report, life cycle cost analyses were done in order to demonstrate the economic benefits of drainage improvements. These LCA results show that drainage improvement is almost always economic. If pavement lifetime can be doubled it is economical to clean the ditches even every second year if need be. Furthermore, solutions more expensive than ditch cleaning alone should always be considered. When starting to improve the condition of problem roads drainage improvement measures should be done 1-2 years before the repaving in such a way that the moisture has time to drain from the materials.

The Roadex drainage report clearly shows that maintaining and improving the drainage system is perhaps the most cost effective measure on roads where inadequate drainage is the main cause of deterioration. As the previous work done in the ROADDEX project has shown, poorly working drainage is one of the biggest problems in the NP area.

The authors of the original Roadex II report “Drainage on Low Traffic Volume Roads”, written by Berntsen & Saarenketo (2005) suggest that inadequate drainage does, in this case, not only mean lack of maintenance but also that the drainage system is not designed according to the guidelines. They further suggest that the existing guidelines can also be insufficient and further improvement of these guidelines should be considered.

References

Berntsen G. & Saarenketo T., 2005. Drainage on Low Traffic Volume Roads. Roadex II report. www.roadex.org



4 Design against permanent deformation

4.1 General

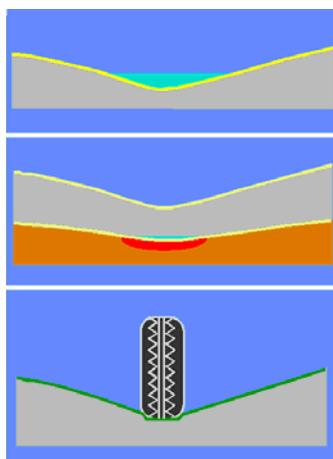
In the study areas of the Northern Periphery, unsealed or thinly-sealed road pavements are very common. Typically, these road structures are constructed from one, or more, layers of crushed stone aggregate laid on top of the subgrade. The surface of these pavements is usually provided by the aggregate compacted to a smooth finish or by a thin bituminous seal into which stones of a uniform size are rolled. Thus, in either case, the aggregate layers provide the chief structural capability of the pavement.

Compacted aggregate is a flexible material. Therefore, if it is too weak, it tends to deform plastically, a little bit of plastic deformation occurring under the passage of each vehicle axle load. Cumulatively this deformation is seen as rutting. In unsealed or thinly sealed pavements, this type of behaviour is a feature of every layer and is greater if the applied stress level, due to traffic, is higher.

The Roadex II phase II report “Permanent Deformation”, written by Dawson & Kolisoja (2004), provides a simple means of evaluating the likelihood of excessive permanent deformation. By this means owners will have an outline approach for assessing existing pavements, for strengthening design and for dimensioning public low volume and private forest road pavements. The study also provides advice to road owners on maintenance and material selection practices which can give rise to poorly performing pavements and those which can give rise to better performance.

4.2 Rutting

Rutting is highly undesirable in a pavement for several reasons (Figure 9). Rutting gives problems to users by increasing the consumption of fuel and the risk of skidding (on water or on ice). It also gives problems to the owner as ruts encourage water to soak into the pavement instead of draining from the surface. Water that enters the pavement in this way may collect in a ‘buried’ rut in the subgrade (Figure 9, b) and reduce the load carrying capacity of the granular layers.



- a) Ponding in a rut allows water to soak into the pavement prematurely, causing its loss of performance. Skid resistance due to aquaplaning and due to ice, when frozen, may result.
- b) Rutting may also be induced at subgrade level allowing water to pond causing (hidden) deterioration of the subgrade.
- c) More friction is developed against the side of the tyre leading to higher rates of fuel consumption and tyre wear.

Figure 9. Reasons why rutting is undesirable.

Furthermore, rutting of the aggregate and/or subgrade layers can lead to failure of the upper asphalt layers. Less directly, rutting is usually not uniform along the length of the road so unevenness develops which leads to user discomfort.

Rutting can occur for a number of reasons. Fundamentally there are four contributory mechanisms, which are labeled in the Roadex II phase II report “Permanent Deformation”, written by Dawson & Kolisoja (2004), as follows (Figure 10):

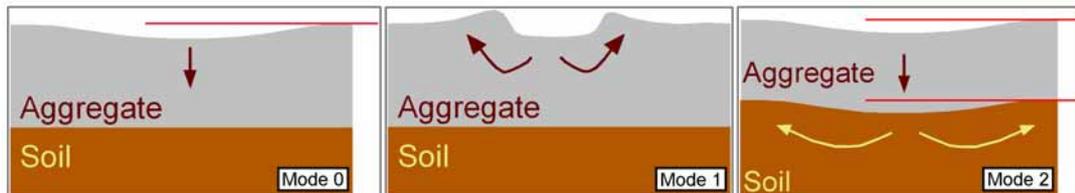


Figure 10. Rutting mechanisms Mode 0 – Mode 2.

- **Mode 0:** Compaction of the granular layers of the pavement only.
- **Mode 1:** Shear deformation within the granular layers of the pavement, near the surface. This gives rise to dilatative heave immediately adjacent to the wheel track. There would be no deformation at the subgrade surface.
- **Mode 2:** Shear deformation within the subgrade with the granular layer following the subgrade.
- **Mode 3:** The same surface manifestation as in Mode 0 rutting contributed by particle damage (e.g. attrition or abrasion, perhaps by studded tyres but more often due to heavy trafficking and turning movements).
- **Combined modes:** In practice rutting will be a combination of the above mechanisms.

All rutting mechanisms are described in more detail in the original report mentioned above.

4.3 The principle study method and results

Two aggregates were tested specifically for the purposes of this project. One was a moderate quality metamorphic aggregate from Scotland - known as “Quarriebraes” aggregate, after its source. The other was a higher quality Norwegian crushed gravel aggregate from Troms. In addition the authors of the report “Permanent Deformation” have drawn on data from several other aggregates from Scotland, N. Ireland, Germany, Finland and Sweden, but especially those from the environmental pavement condition station (‘Percostation’) in Koskenkyla near the city of Rovaniemi in Northern Finland. Together, the data covers a wide range of geological origins, grain size, stone quality, shape, etc. The majority of materials from which the conclusions of this report derive have a crushed rock origin, but some sand and gravel type aggregate have also been studied.

The aggregates have been tested at a range of moisture contents and some were tested after freezing and thawing. The aggregates have also been studied at different grain size distributions. The results were used to calculate the stress conditions in the pavement under typical truck traffic and this enabled an assessment of the likelihood of rutting. The principle study method involved:

- the repeated stressing of cylindrical specimens of compacted aggregate (prepared at a variety of conditions) in triaxial apparatuses,
- interpretation of the results of the triaxial tests in a manner which could be used in an advanced Finite Element computer programme to compute the stresses in pavements constructed of tested aggregates,
- deducing those parts of the pavement structure, and the amount of the pavement structure, which would deform plastically, thereby giving rise to rutting,
- relating the results from simple assessment methods to those from triaxial tests to determine material potential without resorting to advanced laboratory tests,
- drawing general conclusions and advice from the study.

More detailed information concerning the principle study methods is available in original report mentioned earlier.

Stiffness behaviour

The triaxial testing showed a very clear change in mechanical behaviour with added fines and extra moisture. As more water is put into the specimen the stiffness reduces. In practice this means that the aggregate layers of the pavement will not spread the load so well. This means that the stresses on the subgrade will be greater.

Through the analysis of test results it was tentatively suggested that a void ratio greater than 0.33 is required to guarantee that excess moisture will not be held by capillary forces in a granular material and that a void ratio of 0.24 or less is likely to be associated with excess plastic deformation. That is, rutting will be experienced too rapidly, in-situ, by typical granular base layers with such small pore space if water is made available to them (from rainfall, spring thaw or malfunctioning drains).

Plastic behaviour

Figures 11 and 12 show results from the testing of Koskenkylä base aggregate in wet condition (Figure 11) and after thawing (Figure 12). The loading regime is described in the original report "Permanent Deformation". In these Figures, the plastic strain under each successive stress path is shown relative to the strain state of the specimen at the beginning of that stress path.

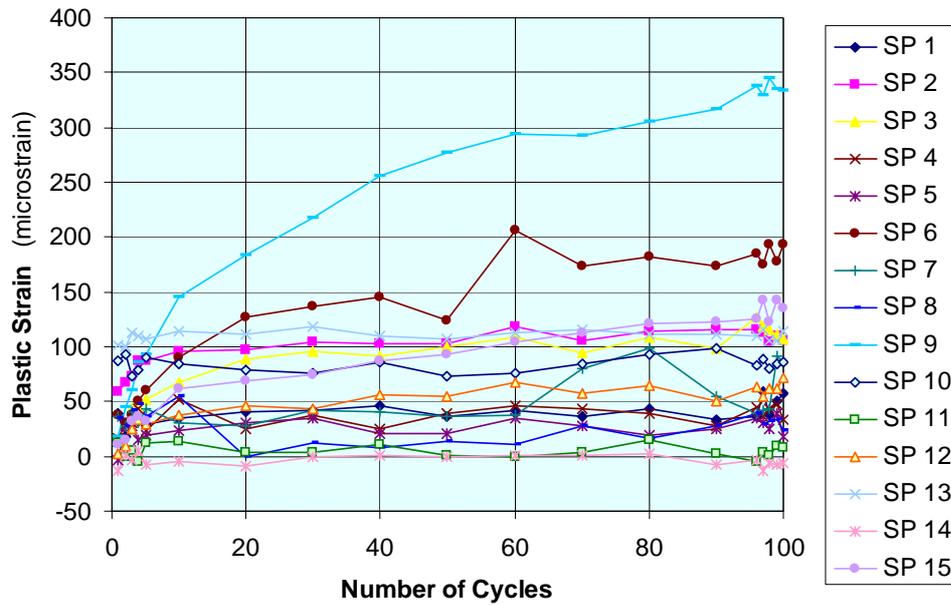


Figure 11. Development of Plastic Strain in a specimen of the Koskenkylä base aggregate in wet condition. 15 stress paths (SPs) have been applied, each of 100 pulses (to simulate trafficking). The stress paths are defined in Figure 13.

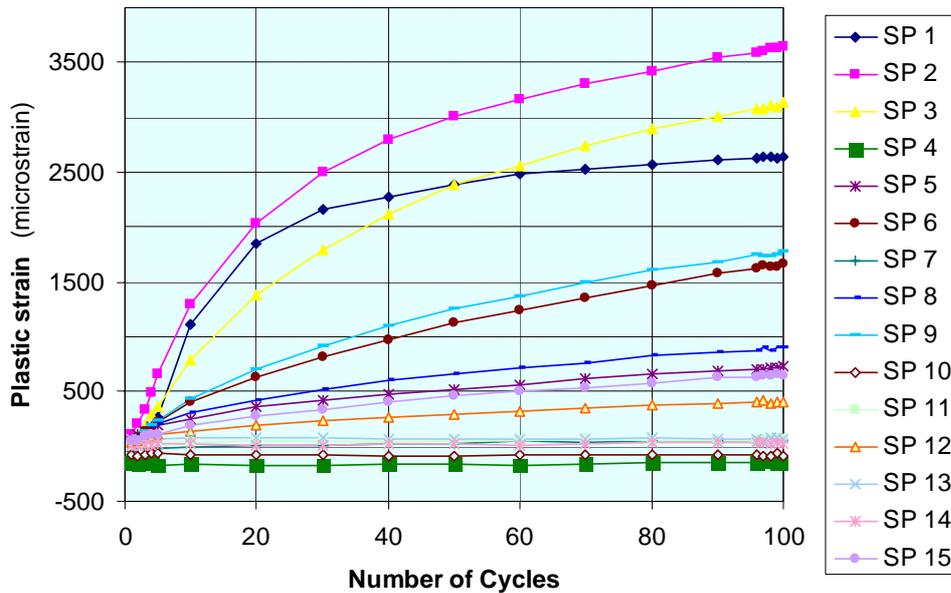


Figure 12. Development of Plastic Strain in a specimen of the Koskenkylä base aggregate after thawing. 15 stress paths (SPs) have been applied, each of 100 pulses (to simulate trafficking). The stress paths are defined in Figure 13. (see different y-scale than in Figure 11)

In Figures 11 and 12, first of all, the very large increase in strain from the wet specimen to the thawed specimen should be noted. To a large extent this is due to the increased moisture consequent upon freezing and in part from densification due to the water pulled in upon freezing. It is obvious from these results that the cycle of freezing and thawing has significantly weakened the aggregate, leading to much higher rates of plastic strain.

Comparing Figures 12 and 13 readily reveals another feature. In Figure 12, once the initial settling of the specimen has been achieved (large plastic strains for Stress Paths 1 and 2) then it is clear that the stress paths which get closest to failure – numbers 3, 6 and 9 – give rise to the highest amount of plastic strain, followed by paths 5, 8 and 15, followed by 12. This sequence confirms that proximity to static failure is a key feature in the development of plastic strain and, thus, to the occurrence of rutting. Figure 11 also shows this stress-related plastic strain dependency, although the pattern is less obvious given the lower strain magnitudes. For the Quarriebraes material, similar results were obtained (although there were no freeze-thaw tests on this material).

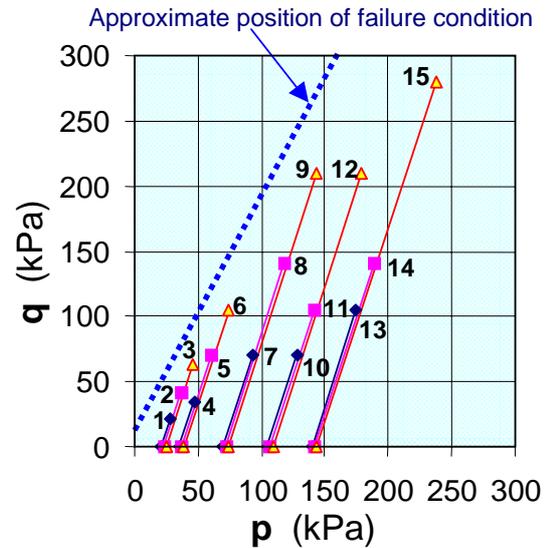


Figure 13. Stress paths used for data presented in figs 11 and 12. The stresses q and p are, respectively the ‘deviatoric’ (i.e. shear) stress ($q = \sigma_1 - \sigma_3$), and the average stress ($=1/3^{\text{rd}}$ of $\theta = \sigma_1 + \sigma_2 + \sigma_3$).

In summary, it has been found from both materials studied in detail in this investigation, and drawing on information available from other sources, that the amount of plastic strain in an aggregate increases:

- When the aggregate gets wetter,
- When the aggregate has been frozen and then is thawed,
- When the stress applied gets closer to the static failure stress condition.

The loss of quality upon freezing appears to be mostly due to increased water content caused by suction developed during freezing and only slightly by a reduction in density due to ice formation. Thus, if the freezing layer is non frost-susceptible then only a slight reduction in performance should be expected in the pavement.

It is less clear whether the fines added always have a direct effect on increasing plastic strain (though sometimes they do), but they certainly have a secondary effect, allowing the aggregate to hold more water. This ability to hold water, due to capillary suction, is undesirably exploited on freezing because cryo-suction effects, which act at the freezing front, are able to pull in more and more water if it available at the edge or bottom of an aggregate layer.

Therefore, for design purposes, taking into account the various findings presented above, it would be sensible to ensure that the stress experienced by the pavement doesn't exceed a certain fraction of the failure stress. Previous researchers have suggested a ratio of $q/q_f = 0.7$ – i.e. the deviatoric (or shear) stress applied, q , is limited to 70% of that needed to induce static failure, q_f , under, in other respects, the same conditions. The data obtained in this study suggests that this may, indeed, be a sensible determination. However, the materials tested in this project suggest that this limit should be set at 50-55% when the aggregate is very wet and fines prevent rapid drainage, or during spring thaw conditions, if the amount of rutting is to be kept small.

At present repeated load triaxial testing would be needed to confirm that the 70% or 50-55% thresholds applied for materials not previously assessed, but assessment could, in future, be achieved by a source-characterisation programme rather than a project-specific one.

The Tube Suction results suggest that a dielectric value of <9 ; or a void ratio of >0.33 in a compacted aggregate are required to ensure that rutting is limited in magnitude (though the data on which to base this recommendation is limited at present).

4.4 The design strategy to prevent permanent deformation

On the basis of the work performed in this project and taking into account the work performed by the authors of the report "Permanent Deformation" and others in previous and associated studies (e.g. Brown and Dawson, 1992) it would be sensible to ensure that the stress experienced by the aggregate layers in a pavement doesn't exceed a certain fraction of the failure stress (see previous section).

To prevent rutting in practice, the following strategy is proposed:

- i. Ensure that compacted aggregate layers have a void ratio of greater than 0.24 (or, if possible, 0.33)
- ii. Check that the tube suction measured dielectric value of the compacted aggregate is less than 10, preferably less than 9, after drying the specimen at 40-50°C and then letting it adsorb water from the base of the specimen.
- iii. If the material satisfies point i, but not point ii, then it should be noted that this source should be processed to produce extra low fines in future or treated as follows.
- iv. If the desired dielectric value cannot be obtained then use the material with special water protection provision. This should comprise a capillary break beneath the aggregate layer in seasonally affected frost areas and, if at all possible, a sealed surface in all locations. This sealed surface should extend beyond the carriageway to maximize the width of sealed shoulders (though full structural capacity is not required there) as research elsewhere (COURAGE, 1999) has indicated the significant benefit of keeping the wetting path as long as possible.
- v. Assess the strength of the aggregate in a wet condition in-situ. This can be achieved by wetting the aggregate in a compacted area (part of the carriageway under construction or, better, a pre-construction trial) and then using the Dynamic Cone Penetrometer (DCP) – see Figure 14. [The DCP has been found to provide a rapid strength determination of aggregate layers and established correlations, Figure 15, are available to allow estimates of strength to be made from the DCP's results]. The DCP is only usable with reliability if the maximum particle size is less than 40mm. For coarser aggregates (e.g. as often used on forest pavements) there is no simple means of assessing the strength. The DCP results must then be converted to a conventional strength assessment in terms of angle of frictional resistance (ϕ) or to a line on a p-q plot. In the absence of a fully quantitative relationship, a classification approach is suggested – see Table 2.

Table 2. Proposed relationship between CBR and Shear Strength Parameters for Base / Sub-base Aggregates.

Class	CBR	DCP Penetration Rate (mm/blow)	Angle of Frictional Resistance (ϕ)	Apparent Cohesion (kPa)
Excellent	>120%	<2.5	>54°	Compute from moisture content alone*.
Good	75-120%	2.5 – 4	50°-54°	
Fair	50-75%	4 – 5.5	45°-50°	
Poor	<50%	>5.5	<45°	

* 20kPa when fully saturated, 40kPa at 80% saturated, 70kPa at 60% saturated.
Data partly obtained from Theyse (2002).

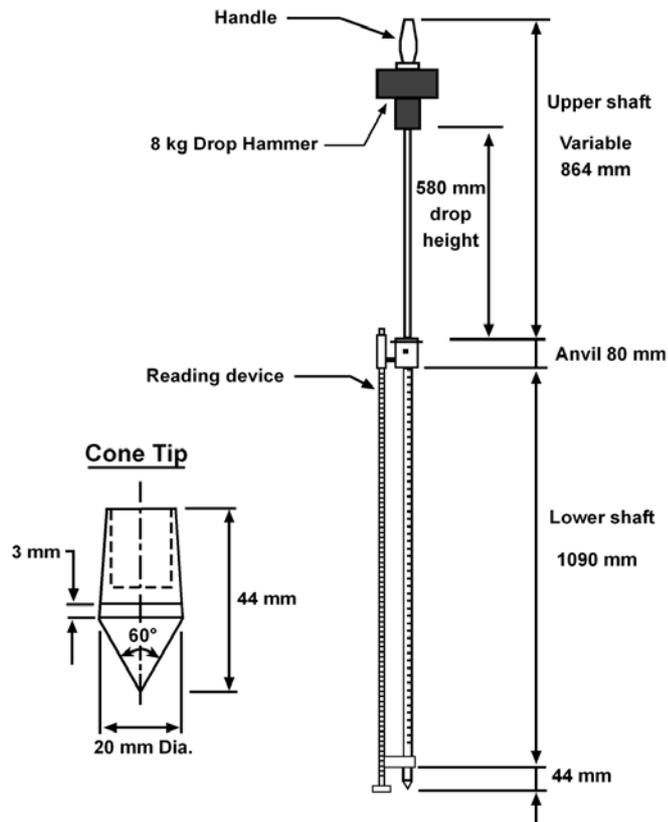


Figure 14. Dynamic Cone Penetrometer, DCP.

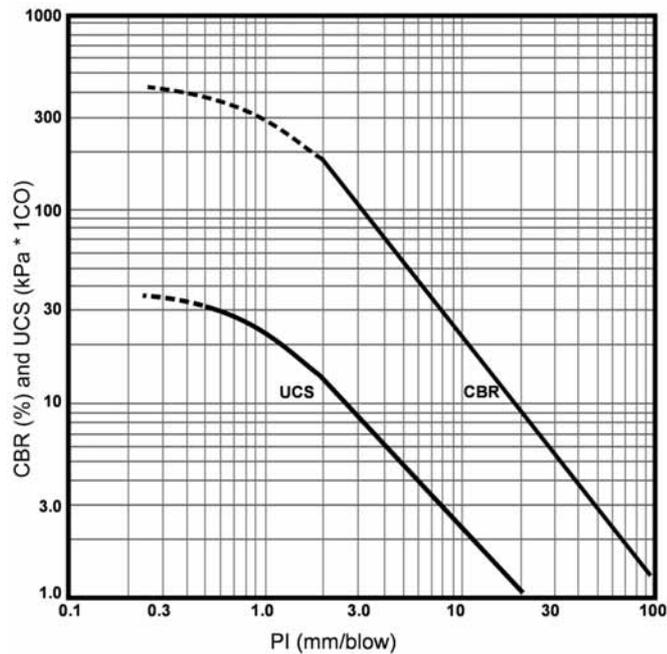


Figure 4.7. Converting from DCP penetration rate (PI) to CBR value or to Unconfined Compressive Strength.

- vi. Design lines are now plotted at 70% and 55% of this limiting value – as in the sample shown in Figure 4.8.

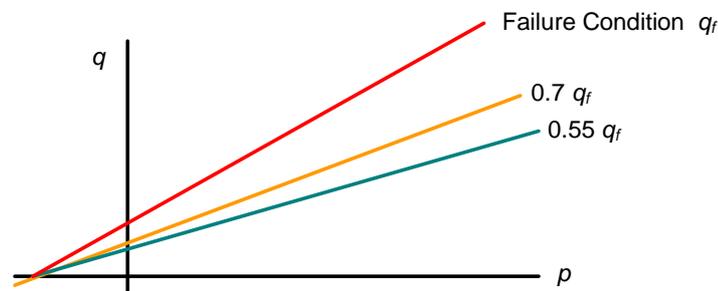


Figure 4.8. Sample design graph.

- vii. Use Boussinesq theory to predict the magnitude of the combination of shear and mean stress for the traffic of concern, which most nearly approaches the boundary lines set in Step vi. This will require a knowledge of :
- The traffic imposed stress
 - The wheel print
- but not of the stiffness of the layer as this is not part of Boussinesq's requirements. The values may be computed from the Figures in the Appendix.
- viii. Plot this computed stress on the version of Figure 4.8, which was previously drawn. Check that the stress condition is not too high.
- ix. If the stress is too great then either replace or treat the aggregate, or add a covering layer. If aggregate treatment is proposed, go to Step i. If added thickness of the bound layer will be the solution then Step vii can be used to predict the new stress state. Some allowance can be made for the extra load spreading effects of an asphaltic layer. It is suggested that asphalt thickness, for the purpose of the Boussinesq calculation can be

treated as 1.5 times as thick as it is actually intended to be when the thickness is less than 60mm and 2 times as thick when the asphalt is thicker than this.

- x. Having designed the aggregate and any overlying layers to prevent Mode 1 rutting, the aggregate thickness must be designed to prevent Mode 2 rutting. The minimum thickness required can be calculated using a layered elastic analysis. Such computational tools are readily available (e.g. the public domain program ELSYM5). The input data for this, however, is a little more difficult to assess. Poisson's ratio values may be assumed (0.35 for aggregate and 0.45 for subgrade soils are typical values). Stiffness modulus values will be needed. The simplest means of collecting such data would be by use of a lightweight falling weight device (e.g. the Prima device) on trial constructions. The results of the linear elastic layered analysis will be an imposed stress on the subgrade.
- xi. The computed vertical stress on the subgrade should be kept to a figure less than 2 times the unconfined strength. The value of the unconfined strength may be determined in several ways. One of the simplest (but not necessarily the most reliable) is to use the DCP-UCS relationship given in Figure 15. The UCS is twice the undrained strength (Cu). Alternatively, specimens may be tested in a laboratory by conventional geotechnical means. However, allowance must be made to ensure that the subgrade is in its worst condition, which can be expected during the pavement life. Thus it may be sensible to test an artificially wetted subgrade prior to construction or to test at a time of spring thaw. The measured unconfined strength should be increased somewhat to allow for the confining effect which will be provided by the completed pavement construction which will ultimately lie on top of the subgrade. This allowance can be made using standard geotechnical bearing capacity depth factors.
- xii. The computations in Step ix are now repeated until the imposed stress onto the subgrade is less than the strength limit described in Step x.
- xiii. In areas affected by seasonal frost Steps ix to xi may not be sufficient. There the depth of aggregate placed to prevent excessive damage – especially unevenness – will almost invariably be greater than that required to ensure structural acceptability. For such pavements the minimum thicknesses in Table 3 are suggested (or greater thicknesses if required by Steps ix – xi).

Table 3. Minimum aggregate thickness in seasonal frost areas.

Subgrade Soil Type	Minimum thickness (mm)
Not frost susceptible	As Steps ix – xi
Moderately susceptible	Greatest of Steps ix - xi or 400mm
Highly susceptible	Greatest of Steps ix - xi or 650mm

Increasing aggregate thicknesses above those given in Table 3 will help to reduce the development of roughness associated with uneven subgrade frost heave. This should be considered for more heavily trafficked pavements and/or those carrying high-speed traffic.

The above procedure does not specifically address durability of aggregate particles. It is assumed that aggregates with very weak stones are not being considered, having been excluded by prior durability assessment using conventional particle durability tests.

5.5 Concluding remarks

The work reported here and the recommendations, which flow from this work are, necessarily, incomplete. The authors of the report “Permanent Deformation” have endeavoured to use the data arising from the study together with published information and their own data from other projects to propose a best method of design. However there are several uncertainties and experience is required to determine the reliability of the approach suggested. In particular the accuracy of the numerical values suggested need greater validation than has been possible in this project.

The issue of fines in an aggregate doesn't appear to have been completely resolved. Where sufficient fines are present, either initially or after trafficking, the granular layer will hold water and the value of q_f will significantly reduce thereby promoting significant in-aggregate rutting. Simple permeability testing might be the quickest and easiest way to determine the acceptable amount of fines that can be held in the aggregate without preventing drainage, especially if the retained moisture after permeability testing is measured. This should be investigated in the future. There is some evidence from this study that higher fines, irrespective of the moisture, lowers q_f , but only strength testing on a range of materials and a range of fines can help with this aspect. The use of the DCP in-situ will assist with this.

Thickness design can use the type of assessments reported here and the simplified Boussinesq design approach suggested as a practical expedience, but a non-linear stiffness analysis is needed to do this meaningfully, thereby requiring more sophisticated testing than is normally or cheaply available. In principle, this should be for both granular layer materials and for the subgrade. In areas where frost is not a great issue (in coastal areas and parts of Scotland) and the aggregate quality reasonable the aggregate thickness will be selected so as not to allow the subgrade to rut (Mode2 rutting). In such circumstances a full non-linear analysis may be necessary or, at minimum a layered analysis with a mean stiffness value determined from laboratory (or perhaps in-situ) testing. Otherwise the stress applied to the subgrade cannot be determined with any accuracy so the required thickness to reduce the stress imposed by traffic, through the granular layers, to an acceptable level cannot be estimated. However in Scandinavia, where deep seasonal frost is of importance, the depth of aggregate placed to prevent excessive damage – especially unevenness – will almost invariably be greater than that required to ensure structural acceptability. For such pavements minimum thicknesses are suggested based on the computed and observed thicknesses, which are successful, but it is recognised that these suggestions are made on the basis of rather limited data. This is an area for further study.

If an overlying asphalt is to be dimensioned, once again, a non-linear analysis is warranted. However, a conservative analysis may be available if a notional, uniform, stiffness for the aggregate is adopted. Then the thickness of asphalt required to reduce the stress near the top of the aggregate to an acceptable level (according to the 70% or 50-55% of q_f discussed above) can be estimated. A problem with this is that the sensitivity to conservative assumptions isn't known and this could deliver artificially thick asphalt layers. Again, this is an area for future study.

References

Brown, S.F. and Dawson, A.R., 1992. Two-stage approach to asphalt pavement design. Proc. 7th Int'l. Conf. Asphalt Pavements, Nottingham, June, Vol. 1, pp. 16-34.

Dawson A. & Kolisoja P., 2004. Permanent Deformation. Roadex II report. www.roadex.org

COURAGE, 1999. Construction with unbound road aggregates in Europe. final report to European Union, University of Nottingham. (see www.nott.ac.uk/courage).

Theyse, H., 2002. Stiffness, strength and performance of unbound aggregate material: Application of South African HVS and laboratory results to California flexible pavements. Univ. of California, Pavement Research Center, 86pp.

Appendix 1 – Stress Plots

A stress analysis program was used to compute the stresses in a semi-infinite layer of constant modulus and Poisson's Ratio of 0.35 for a surface load applied over a circular area of radius 1m. Stress evaluations were made at a grid spacing of 0.1m horizontally and vertically over a radius and to a depth of 3m.

A selection of the results has been plotted as Figures A1 and A2. The first figure (Fig. A1) plots values of mean normal stress, p , normalised with respect to the surface loading. The second (Fig. A2) plots the deviatoric stress. Again, q is shown normalised with respect to the applied surface load.

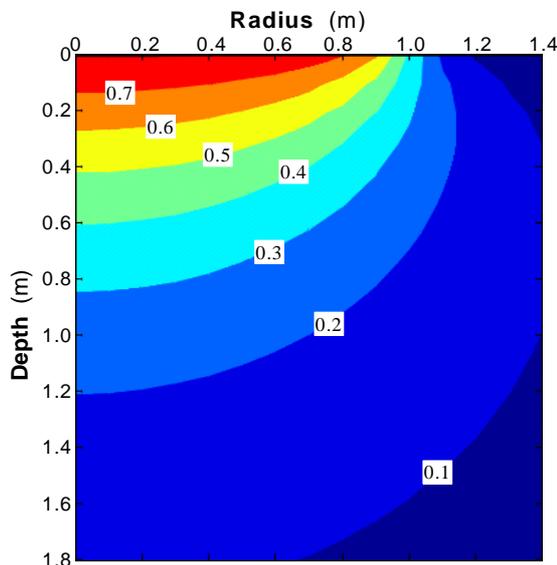


Figure A1 Non-dimensional values of p

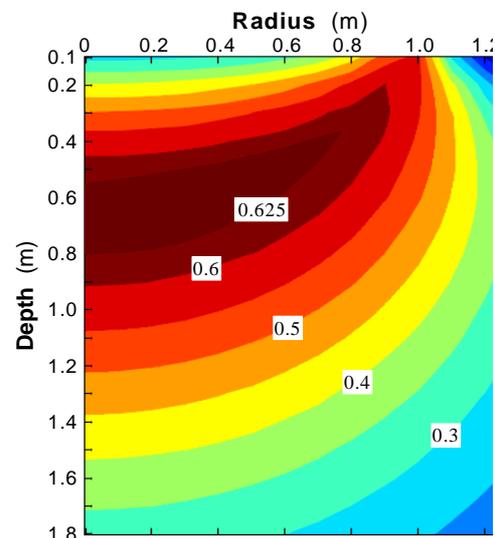


Figure A2 Non-dimensional values of q

Contours shows fraction of applied surface stress at intervals of 0.1 (p) and 0.05 (q).



5 New survey, laboratory and treatment techniques

5.1 General

Within the Roadex II project some new or not so well known survey, laboratory and treatment techniques were used. The experiences seemed to be so good that these techniques could also be considered for road condition evaluations in future. However, it should be realised that there is still research work to be done related to some of the methods used before the methods can be utilised in a controlled manner. In the following sections a brief review of new survey, laboratory and treatment techniques is given.

5.2 Percostation

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 1995) and later to measure the water susceptibility of base aggregates (Saarenketo 1995, Saarenketo and Scullion 1996). Currently, the Percometer is most commonly used for taking measurements in the Tube Suction Test (TST) (described in next section). 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 16. 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, which is in contact with the ground. 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 $< 1000 \mu\text{S}/\text{cm}$.

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 16).

Percostation technique is mainly used in Roadex II subproject "Spring Thaw Weakening". Detailed Percostation data analysis can be found in Roadex II report "Managing Spring Thaw Weakening on Low Volume Roads", written by Saarenketo & Aho (2005).

5.3 Tube Suction test, TS -test

The Tube Suction (TS) test method, originally suggested by Saarenketo (1995) and Scullion and Saarenketo (1997), is an easy to perform laboratory test method for assessing the water suction properties of various types of aggregates. The test includes compaction of a 180 to 200 mm thick aggregate sample in a plastic tube with an internal diameter of 150 mm. After the specimen has been dried it is put into a plastic tube with a layer of water at the bottom. The absorption of water into the specimen is then monitored by measuring the dielectric value and electrical conductivity at the top of the specimen at frequent intervals (Figure 17). A more detailed description of the test method is given by Saarenketo (2000).

The TS-test was used in the Roadex II subprojects “Permanent Deformation” and “Material Treatment”. Based on the experiences of TS test usage in subprojects it seems that the test can be used to assess the sensitivity of the aggregate’s behaviour to the moisture condition. It can be used for simple laboratory studies a priori or for in-situ assessments to establish the current condition of an unsealed pavement. The TS test also seemed to be a very useful tool for making a preliminary assessment of the applicability of the various types of treatment agents for stabilisation. The test is already used as a routine survey method for instance by the Texas Department of Transportation.



Figure 17. Measurement of the dielectric value and electrical conductivity of the upper part of the Tube Suction test specimen.

5.4 Dynamic Cone Penetrometer, DCP

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 18). 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.

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 module values using a formula used by the Norwegian Road Administration (Roadex CD-ROM).



Figure 18. DCP tests at Kemijärvi test site in spring 2004 using the Norwegian DCP system.

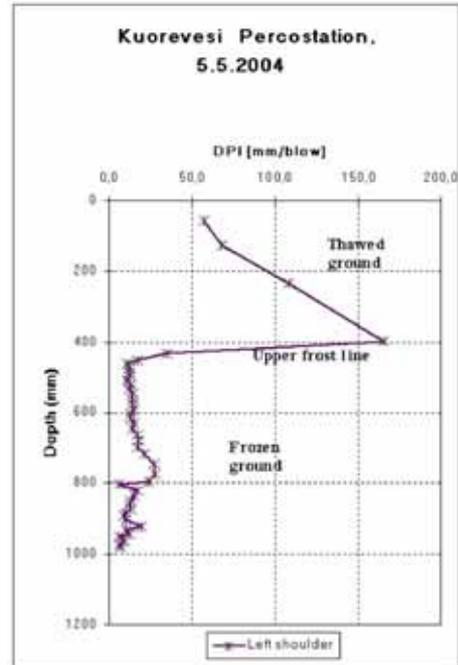


Figure 19. DPI profile measured at Kuorevesi test site on 5.5.2004. The profile shows the upper frost line at the depth of 400 mm.

It should be known that the module values calculated from the DCP test results are not directly comparable with the module values calculated from the FWD data. The FWD provides dynamic module values while DCP module values are based on the shear strength. The DCP module values however provide a good view of the relative stiffness of the road structure and subgrade at different depths and locations on the cross section profile. Thus the DCP results can also be used to measure the depth of structural interfaces in a road structure.

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 tests 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. Figure 19 presents a DPI profile measured at the Kuorevesi test site on 5.5.2004.

5.5 Material treatment techniques on low-volume roads

5.5.1. General

Task 2.2 of the Roadex II Project “Material Treatment” deals with the available methods that can be used in improving the performance of the structural layers, especially the base course layer, of the low volume roads in the Northern Periphery (NP) area. The main emphasis is on the so called non-traditional treatment agents and methods that can potentially provide cost-effective alternatives to the traditional stabilisations performed using hydraulic and bituminous binding agents. Since the main problem, to which the new material treatment methods are being applied, is permanent deformations on low volume roads, the task has been done in close co-operation with Task 2.1 “Permanent Deformation”. The final report of Task 2.2 attempts to make a concise summary of the current knowledge concerning the types of non-traditional treatment agents available and to assess their applicability in treating the base course materials of low volume roads in the NP area.

Because the overall thickness of the structural layers in the low-volume roads is usually relatively low, the significance of the base course is emphasised. This is also the reason why research done in Task 2.2 deals mainly with the base course layers and materials used in low-volume roads. These base course materials are assumed to have a fines content less than 20 per cent which is the typical situation at least in the Nordic countries in which higher fines contents are clearly unacceptable due to the effects of seasonal frost. The aim of the final report “Material Treatment”, written by Kolisoja and Vuorimies (2005) is to make an assessment of the commercially available non-traditional stabilization agents used to reduce the water-susceptibility of the base course materials. The assessment is based on information gathered from a literature survey, information available on the www-pages of the treatment agent producers, results of laboratory tests done in connection with this subproject and last, but not least, results from a national research project that has been running parallel to this subproject at the Tampere University of Technology.

5.5.2 Traditional treatment techniques

Stabilisation of the base course layer using cement or bitumen is a well-known method used to improve the bearing capacity of roads. In the conditions typical to the Northern European countries the traditional stabilisation methods have been observed to be fairly effective if the fines content of the materials does not greatly exceed 10 percent. The method is, however, usually too expensive to be used very extensively on the low-volume roads.

The main aim in the use of the traditional stabilizers has been to increase the strength of the treated layers. The most traditional stabilizing agents are pozzolanic materials like cement and lime. The use of cement and lime in stabilization has been studied for a long time and in many countries codes of practice are available. In Finland, for instance, the design codes for cement stabilization present the range of grain size distribution of the base course materials on which cement stabilization can be used. Cement stabilisation produces a base course with high stiffness but it is, however, fragile. Therefore, the technique is normally not suitable for improving low volume roads located on frost-susceptible subgrades.

Nowadays bitumen is also frequently used in improving the technical properties of the base course materials. In bitumen stabilization 3 to 4% of the mass, of either foamed or emulsified bitumen, is mixed with the material to be treated. As an example, once again according to the Finnish design codes, emulsified bitumen can be used if the fines content of the material to be treated is 5 to 8 %. Correspondingly, foamed bitumen can be used if the fines content is less than 12 %.

The range in grain size distribution of the materials suitable for cement or bitumen stabilisation is presented in Roadex II report “Material Treatment”, written by Kolisoja & Vuorimies (2005).

5.5.3 Non-traditional treatment techniques

Besides the traditional stabilisation methods one potential alternative for the future is the use of the non-traditional stabilisation techniques i.e. treatment of the base course layer with additives that aim towards improving the performance of the road structure e.g. by making it less sensitive to the effects of water, which is commonly the main cause of the permanent deformation problems. Some of these new types of treatment agents may even enable the use of locally available lower quality materials and thus a marked reduction in the use of good quality materials and the related transportation costs.

A significant amount of development work on non-traditional stabilisation agents has been done in arid and warm climates. The work has concentrated mainly on aggregates with plastic properties, which have quite a high fines content and a certain minimum amount of clay particles. The main aim of many of the products has been to reduce plastic properties and ease compaction to achieve higher densities, which will increase the bearing capacity of roads and reduce the loss of material.

According to the usage guidelines provided by the manufactures, the treatment techniques used with non-traditional stabilizers are not significantly different than those used with the traditional ones. Some are easier to use and some might be a little more difficult. In liquid form some non-traditional stabilizers are easier to mix and also cleaning of the machines will be easier.

Until now the classification of treatment agents has not been established. The classifications that are used are greatly affected by the differences in local practises and if the experiences are primarily based on dust-suppression or on stabilisation of subgrade materials. In performed subproject the non-traditional treatment agents tested for base course aggregates were divided into the following classes:

- 1) polymers,
- 2) enzymes,
- 3) ionic treatment agents,
- 4) lignins,
- 5) resins and
- 6) other types of stabilisers.

In addition, the group of combined treatment agents could be added including materials clearly consisting of more than one group of material.

A brief description of each class is presented in an original report "Material Treatment", written by Kolisoja & Vuorimies (2005).

5.5.4 Test methods

The tests performed included experiences from laboratory scale tests with four different crushed rock aggregates from Finland, Lådesglo, Lepoo, Emet and Lillby, one crushed gravel aggregate from Norway, Troms, and one crushed rock material from Sweden, Angesby. A brief description of each test material is given in report "Material Treatment", written by Kolisoja & Vuorimies (2005).

The tests consisted of Tube Suction tests (TS, see chapter 5.3) and a limited number of repeated load triaxial (RLT) tests simulating the effect of seasonal variations. The cyclic loading tests were performed using the large scale repeated load triaxial testing facility developed earlier in the Laboratory of Foundation and Earth Structures at Tampere University of Technology as described by Kolisoja (1997). Testing of the mechanical behaviour of the aggregates was done in several stages. In between the consecutive tests stages the specimens were exposed to treatments that simulates the effects of the seasonal variations that occur in real pavement structures. The test procedure is described detailed in the original report.

Unfortunately, well documented long-term test results concerning the in-situ performance of the non-traditional treatment agents are very sparsely available. The lack of long-term experiences concerning the effect of various types of treatment agents also applies to the laboratory test results.

5.5.5 Conclusions of the test results

The main conclusions that can be drawn regarding the application potential of the non-traditional treatment agents in improving the performance of the low volume roads in the Northern Periphery area are as follows:

- Most of the commercially available treatment agents require a great proportion of fines to be efficient and, therefore, are probably not very applicable for base course materials in areas with seasonal frost action.
- Many treatment agents require fairly long curing/drying times. This limits their potential usage in moist climates.
- Enzymes and ionic stabilisers are not recommendable for use on coarse grained materials, but they may be efficient on fine grained soils.
- Polymers are the largest commercially available group of stabilisers. Based on the experiences in connection with this research, it seems that the most promising stabilisers in reducing the effects of moisture and freeze-thaw cycles can be found in this group. At least the polymeric treatment agent that was tested performed very well with Lillby and Troms aggregates. It is also claimed that polymers are environmentally friendly.
- Clearly the non-traditional stabilisers have potential to become technically and economically competitive alternatives in the rehabilitation of low-volume roads in the Northern Periphery area. However, quite a lot more research should still be done, since the current trial and error approach, which does not take into consideration fundamental reactions in treated structures, may lead to false conclusions. It is in this way that many potentially useful stabilisers are found to be unfit.

It is obvious that different types of treatment agents are needed for different types of aggregates and soil materials. In addition to the classification of the treatment agents it also seems necessary to classify the aggregates and soil materials into at least four different categories. Non-plastic coarse grained materials could be divided in two classes based on the fines content of 5-12% and 12-25% respectively. In addition, the plastic fine-grained materials could also be classified in two classes. In one of the classes the fines content could be 15-30% and the plasticity index less than 10 (12) while the other class would include the materials containing more than 25% fines and having a plasticity index higher than 10 (12).

Both the results of TS and RLT tests indicate that even a fairly small amount of bitumen, 2 to 3 % and in some cases only 1 %, can markedly reduce the water suction tendency of a problematic base course aggregate and thus improve its performance under a repeated loading corresponding to the effect of heavy vehicles even during the thawing period of seasonal frost.

Based on the experiences thus far, it also seems that the Tube Suction test is a very useful tool in making a preliminary assessment of the applicability of the various types of treatment agents. On the other hand, however, it should be realised that there is still much research work to be done in this area before the non-traditional treatment agents and methods can be utilised in a controlled manner. One vital aspect of this additional research would be the construction and monitoring of full-scale test sites from which it could be possible to obtain reliable information concerning the long term performance of treated structural layer materials in realistic environmental and loading conditions.

References

- Dawson A. & Kolisoja P., 2004. Permanent Deformation. Roadex II report. www.roadex.org
- Kolisoja, P., 1997. Resilient deformation characteristics of granular materials. Doctoral thesis, Tampere University of Technology, publication number 223, 216 p.
- Kolisoja, P. & Vuorimies N., 2005. Material Treatment. Roadex II report. www.roadex.org
- Roadex I Project 1998-2001. Northern Periphery. CD-ROM.
- Saarenketo, T., 1995. Using electrical methods to classify the strength properties of Texas and Finnish base course aggregates. Center for Aggregates research, 3rd Annual Symposium Proceedings, Austin, Texas, 19 p.
- Saarenketo T., 2000. Tube Suction test – results of round robin tests on unbound aggregates. Finnish National Road Administration, Lapland Region, report number 19/2000. 42 p.
- Saarenketo T. & Aho S., 2005. Managing Spring Thaw Weakening on Low Volume Roads. Roadex II report. www.roadex.org
- Saarenketo T. and Scullion T., 1996. Laboratory and GPR tests to evaluate electrical and mechanical properties of Texas and Finnish base course aggregates. Proc. of 6th International Conference on Ground Penetrating Radar, Sendai, Japan. pp. 477-482.
- Scullion, T. & Saarenketo, T., 1997. Using suction and dielectric measurements as performance indicators for aggregate base materials. In Transportation Research Record 1577, TRB, National Research Council, Washington, D.C., pp. 37- 44.



6 Structural solutions for spring thaw weakening

6.1 Introduction

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 weakening
- 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
- 4) cooperation with transportation organizations using heavy vehicles
- 5) heavy vehicle technologies such as Central Tyre Inflation (CTI), special axle configuration systems and Automatic Vehicle Identification (AVI)

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.

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 reappear. 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.

In the following, general aspects of classification and descriptions of different problem sites are presented. The classification method can be used for basic problem diagnostics and selecting the optimum rehabilitation method. A classification method based on topography and drainage condition is discussed in the Roadex II phase II report “Drainage on Low Traffic Volume Roads”, written by Berntsen & Saarenketo (2005). Also maintenance and structural solutions that have been used successfully to deal with spring thaw weakened roads will be discussed in the sections that follow. The topic of spring thaw weakening is discussed in detail in the Roadex II phase II report “Managing Spring Thaw Weakening on Low Volume Roads”, written by Saarenketo & Aho (2005).

6.2 Spring thaw weakening damage site classification

6.2.1 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 20). Softening takes place through the cross section. Differential frost heave bumps are also 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 presented in chapter 6.4.2 have also been used successfully.

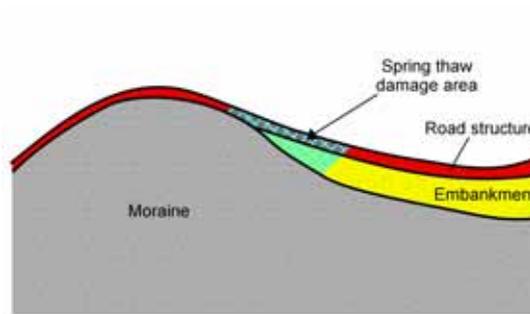


Figure 20. Typical location of spring thaw problem site on a gravel road over a morainic hummock.

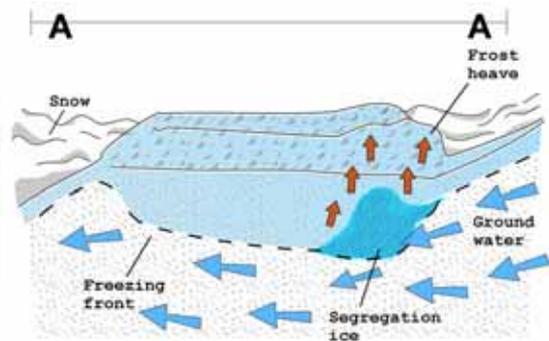


Figure 21. A schematic figure of the development of spring thaw damage on a road located on transversely sloping ground in an area where ground water is close to surface.

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 21). 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 6.4.2).

6.2.2 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 was 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 these 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 22).

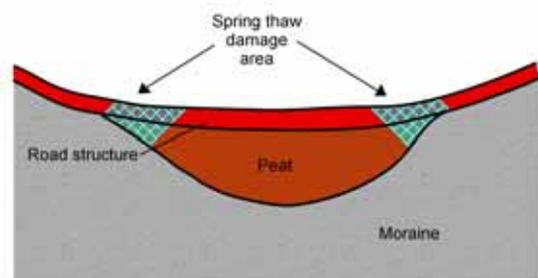


Figure 22. Location of spring thaw damage in road sections resting on peat.

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. Reinforced structures containing a steel grid are presented in section 6.4.6.

6.2.3 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 23).

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.

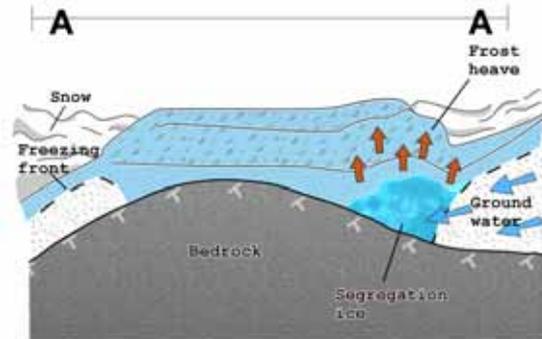


Figure 23. A schematic figure of a road cross section with spring thaw damage problems due to the presence of bedrock.

6.2.4 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 24 presents 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 variations in 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 place 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.

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 it is also important not to strengthen the road over the widened road shoulders unless they have been repaired first. The best and most economical solutions have proven to be structures 2-4 presented in chapter 6.4.2.

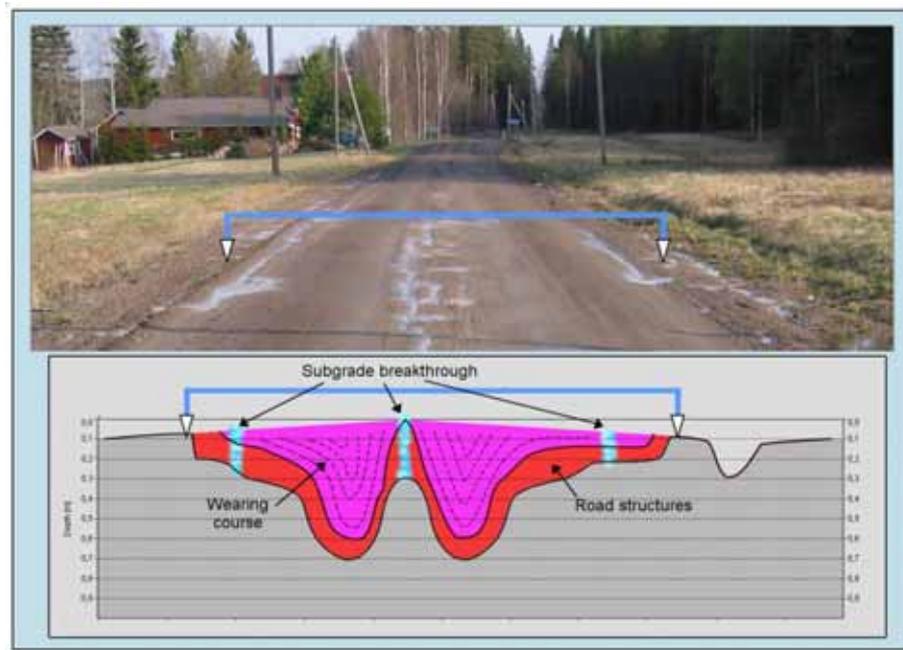


Figure 24. A typical cross section of a gravel road with spring thaw damage problems that is located on a silty subgrade.

6.2.5 Others

Other special sites with spring thaw problems can be related to a clogged lateral culvert located on side-sloping ground 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 (see chapter 2). 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.

6.3 Spring thaw damage maintenance techniques

6.3.1 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 water from melting 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). According to the general practise, ditches are cleaned at approximately 8-11 year intervals but this analysis and the analysis made by Berntsen and Saarenketo (2005) indicate that the interval should actually be much shorter.

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 braking by heavy vehicles. This type of situation creates a definite 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 "Drainage on Low Traffic Volume Roads" written by Berntsen & Saarenketo (2005).

6.3.2 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 roads 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 is 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.

The excessive use of dust binding chlorides, during routine maintenance of gravel roads, 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.

6.3.3 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 & 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.

6.4 Spring thaw damage strengthening techniques

6.4.1 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 Ångesby Percostation site in Sweden is a good example of a road where the problems have decreased following the change back to gravel.

6.4.2 Basic structural options for repairing spring thaw damage on gravel roads

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

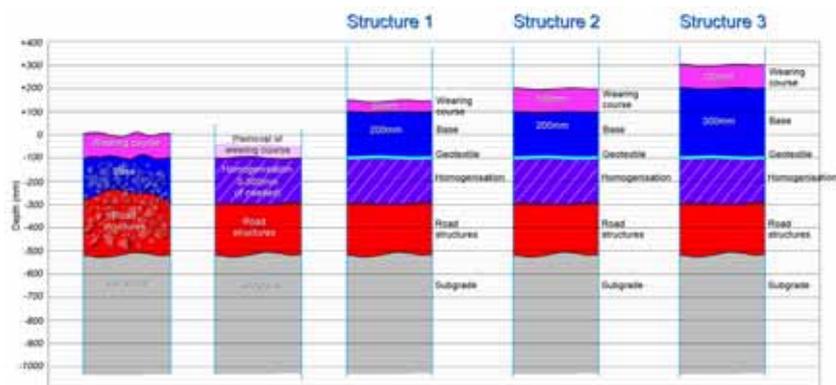


Figure 25. Basic structures 1-3 used in gravel road strengthening projects in Finland. A more detailed description of the structures is given in the text.

fabric) + 200 mm of base course + 50 mm of wearing course. This structure is described in Figure 25 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, Ryyänänen 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 (0-14 mm) has been recommended as a method of repairing such a structure.



Figure 26. Homogenization of the top 200 mm of the structure. (photo: T. Ruohomäki)

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 26) 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. 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 for repairing spring thaw damage on gravel roads is a structure that reaches a depth 400 – 500 mm from the road surface.

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 25 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

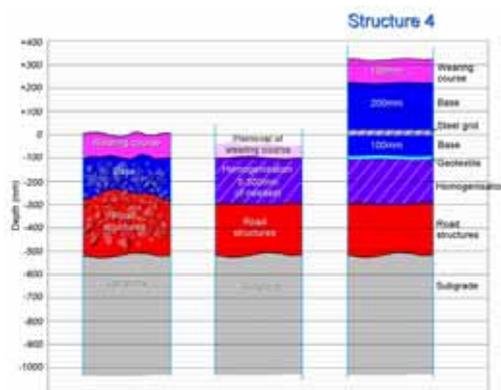


Figure 27. Structural option 4, steel reinforcement.

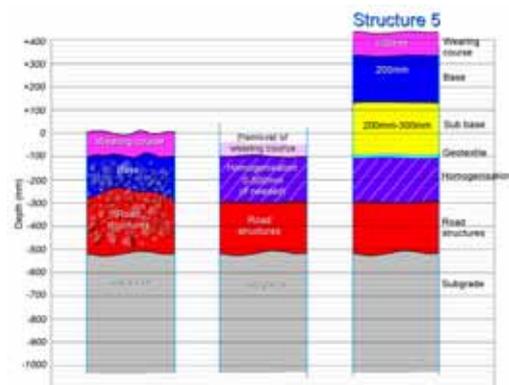


Figure 28. Structural option 5, 500 – 600 mm thick new structures.

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 done by raising the grade line using 500 – 600 mm thick new structures (see figure 28 structure 5). Due to the risk of differential settlements, the use of such thick structures should be carefully considered 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 27 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 unwanted 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.

When spring thaw damage is severe and difficult, differential frost heave can also be found in the same section. The only way to solve the problem, in many cases, is soil replacement (for instance structure 6 in Figure 29.). Due to the extra thick structures 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.

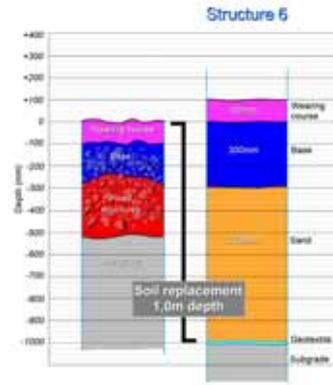


Figure 29. Structural option 6, soil replacement 1 m depth.

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 life cycle costs higher. Life cycle 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 30). Naturally the most expensive one is soil replacement to a depth of 1 m (structure 6).

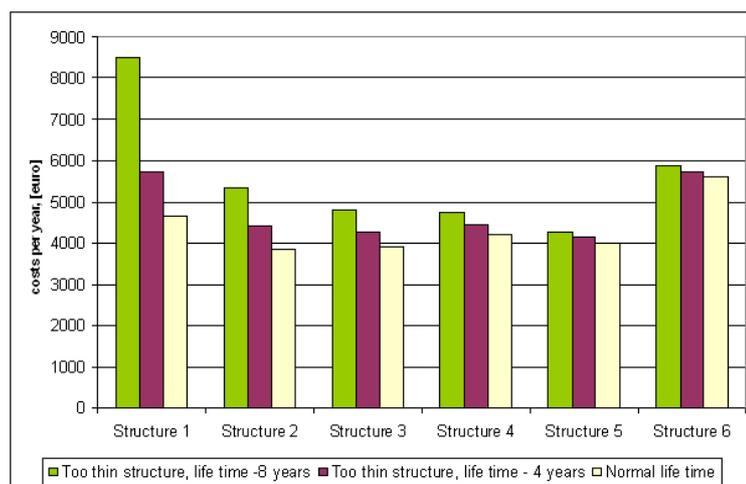


Figure 30. Structural options 1 – 6 and their lifetime costs per year. (Aho 2004)

According to the analysis results, the thinnest structural options (structures 1–2) are more sensitive to variation of their lifetime (see Figure 30). If the constructed structure is not strong enough to deal with spring thaw damage, the lifetime of the structure will be shorter (presented in figure 30 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 vehicles driving on this firm looking shoulder will cause failures. Figure 31 presents a typical cross section that will fail and a cross section illustrating how strengthening should be done.

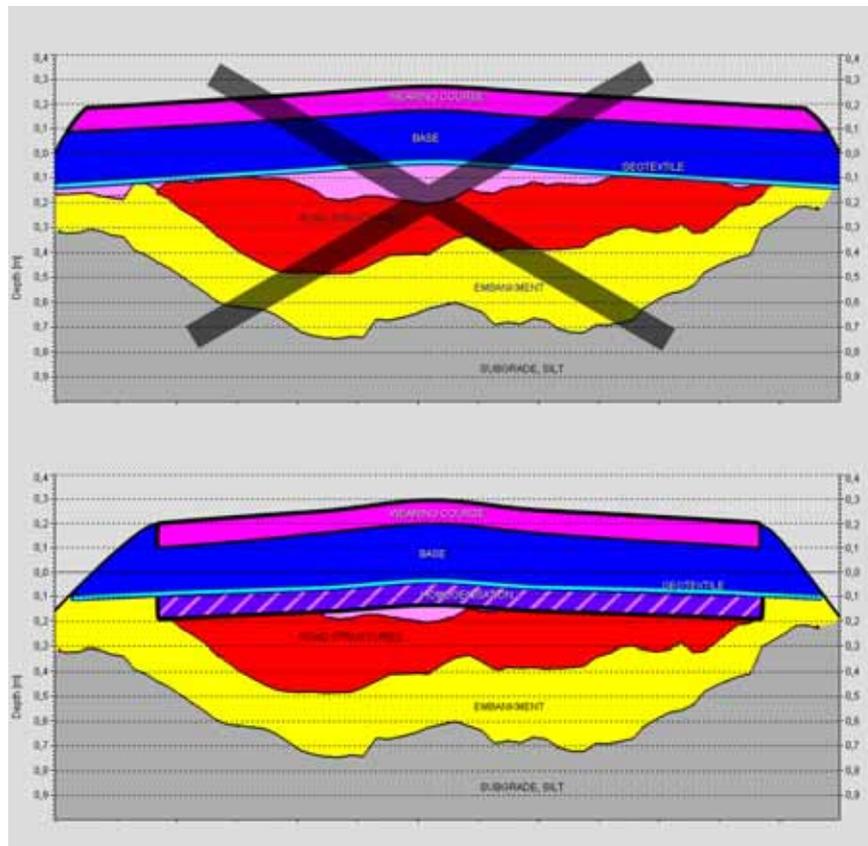


Figure 31. Typical cross section that will fail and a cross section showing how strengthening should be done.

6.4.4 Homogenisation

If a road owners has 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. However, because this method only homogenises the top part of the pavement structures it should be considered as a short term solution for strengthening the structures.



Figure 32. Mixing the current pavement with the base course.

In the execution of this procedure the current surface dressing is first mixed with the base course (Figure 32). 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 such 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.

6.4.5 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 (Kolissoja & Vuorimies 2005).

More information about stabilization and treatment techniques is given in chapter 5 and in the Roadex II report “Material Treatment” written by Kolisoja & Vuorimies (2005).

6.4.6 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 at 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 27.

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 26. 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 / 0-55mm) 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 33). 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 33. Base course is laid over steel grid. (photo: T. Ruohomäki)

Calculations made by Aho 2004 showed that the use of steel grid in a structure corresponds about 70 – 80 mm thick unbound base course layer. More detailed description of the calculations is given in original report “Managing Spring Thaw Weakening on Low Volume Roads” written by Saarenketo & Aho (2005).

6.5 Summary and conclusions

As already mentioned 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 and Aho 2003) revealed that great number of the sections that receive emergency repairs fail again the following spring. That is the reason 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.

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. Gravel road rehabilitation and strengthening design is quite straightforward when the cause of the damage has been well researched. 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 roads is to improve the drainage system and maintain it in good working order. Different drainage techniques have been reported in great detail in chapter 2 and in another Roadex report, “Drainage on Low Traffic Volume Roads” (Berntsen & 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).

The original Roadex II report “Managing Spring Thaw Weakening on Low Volume Roads” written by Saarenketo & Aho (2005) also 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 also reveals new and promising technologies that heavy trucks can use to reduce the stresses on the road structures during the spring thaw period.

References

- Aho, S., 2004. Sorateiden kelirikkokorjausten toimivuus ja elinkaarikustannukset. Diplomityö, Tampereen teknillinen yliopisto. Tampere. (English abstract)
- Kolisoja, P. & Vuorimies, N., 2005. Material treatment. Roadex II report. www.rodex.org
- Roadex Project 1998-2001. Northern Periphery. CD-ROM.
- Ryynänen, T., Belt, J. & Ehrola, E., 2003. Sorateiden runkokelirikko ja kelirikon vaikeuden ennustaminen. Tiehallinnon selvityksiä 46/2003. (in Finnish)
- Saarenketo, T. & Aho, S., 2005. Managing Spring thaw Weakening on Low Volume Roads. Roadex II report. www.rodex.org
- Saarenketo, T. & Aho, S., 2003. Kelirikkoteiden painorajoitusten yhtenäistäminen, Tiemestari-kysely-tutkimuksen raportti. Roadscanners Oy. Rovaniemi, Tampere. (in Finnish)
- Saarenketo, T. & Vesa, H., 2000. The Use of GPR Technique in Surveying Gravel Road Wearing Course. In Eighth Intl. Conference on Ground Penetrating Radar, David A. Noon, Glen F. Stickley, Dennis Longstaff, Editors, SPIEE Vol. 4084. p. 182 – 187.
- Zarghampour H., Elsander J., Kolisoja P., Lechner B. & Nesslerauer S., 2002. Modelling of Flexible Pavement Reinforced by Steel Net. REFLEX Report T7:02. Final Report.



7 Structural solutions for road construction over peat

7.1 General

The construction of roads over peat presents great challenges to the intending road builder not only in the landscapes and terrain that have to be crossed but also in the management of the engineering properties of peat of high water content, high compressibility and low strength. The roads engineer has to overcome these engineering obstacles and considerations of low bearing capacity and excessive settlement in order to be able to construct safe, stable and serviceable road embankments.

Recently, in the last 10 to 20 years, an awareness of the "usability of peat" as an engineering subgrade has reappeared, particularly in those geotechnical communities in countries with large peat deposits, and especially in the Northern Periphery where the "green issues" of earthworks construction have become increasingly important within the public domain. Issues such as the proliferation of quarries, loss of agricultural land and recreational space and the amenity of landscape continue to gain a much higher public profile whilst budgets for roads reduce commensurately. For these reasons an increasing number of geotechnical engineers are actively pursuing more cost effective and innovative solutions for roads constructed over peatlands.

7.2 Engineering considerations

The selection of a construction method for a road over peat will normally be based on economic considerations coupled with the performance requirements expected of the new carriageway. It has long been recognised that the consolidation and settlement of peat under load is an extremely complex process and a major practical problem for the intending road builder to predict and quantify the likely magnitude and rate of consolidation and settlement to be expected. Irrespective of which end of the performance spectrum the particular road embankment happens to lie it will have to be designed to meet the two main engineering criteria of embankment stability and settlement.

All embankments need to be designed to be stable and be constructed in such a fashion so as to produce a sufficient factor of safety against foundation and sideslope failure. This failure can be by; failure of the underlying peat along a slip surface, normally in the form of an arc; or punching shear into the underlying peat where the embankment settlement is accompanied by heave of the adjacent peat bog alongside the embankment. Appropriate analyses should be carried out ahead of the construction works to ensure that these failure conditions are avoided.

Various forms of proprietary stability analyses are available on the geotechnical market and Internet such as PLAXIS, OASYS, FLAC, SAGE, etc. The selection of the most suitable method of analysis (spreadsheet, general analysis, finite difference/finite element analysis, 2 dimensional, 3 dimensional, etc) should be left to an engineer experienced in the field. As part of this analysis it will be necessary to examine the short term construction stability of the embankment, including the effects of the different phases of the embankment construction, as well as the long term stability of the chosen method of construction. Embankment stability is unlikely to pose a design problem on fibrous bog peats however due to the reinforcing effect of the peat fibres but it can be a significant consideration in the design and performance of embankments over fen peats which tend to be more humified and less permeable.

The settlement of an embankment on peat is considered in 2 parts; magnitude and rate of settlement. The rate of settlement, and the time needed for the embankment to settle, is normally the more important consideration of the 2 parameters for a road related project if future post-construction maintenance is to be minimized. The early estimation of the magnitude and rate of settlement is therefore a significant factor in a successful embankment over peat.

Peat exhibits an immediate 'elastic' settlement as soon as it is loaded and a 'consolidation' settlement thereafter. It is possible to estimate the 'immediate' settlement element but most authorities in the Northern Periphery choose to ignore this elastic element and concentrate their efforts in assessing the magnitude of the 'consolidation' settlement as this has a far greater effect on the serviceability of the finished road. An embankment on peat settles (consolidates) in 2 stages; the 'primary' consolidation stage as the pore water is squeezed out of the peat mass and the 'secondary compression' stage as the internal peat matrix slowly takes an increasing share of the embankment load as it increases in strength. These phases can be estimated by a number of means but all methods produce only general predictions. Site instrumentation is considered essential to check that settlements on site are proceeding as predicted.

7.3 Types of construction on peat

7.3.1 General

This chapter aims to present the general aspects of structural solutions presently available to the practising road construction on peat.

Construction over peat can essentially be sub-divided into five broad classifications:

- 4.3.2 Avoidance
- 4.3.3 Peat excavation
- 4.3.4 Peat replacement
- 4.3.5 Peat displacement
- 4.3.6 Peat left in place

The original report "Dealing with Bearing Capacity Problems on Low Volume Roads Constructed on Peat", written by Munro (2004), describes all techniques detailed indicating some of the advantages and disadvantages associated with them. The report includes also case histories from road projects, with particular reference to those currently being considered and promoted by roads professionals in the Northern Periphery.

7.3.2 Avoidance

The first method of dealing with peat is to avoid it. If circumstances permit (alignment, environment, economics, etc) any engineer faced with crossing a peatland has to consider going round the obstacle. This option requires an alignment revision, which is not always possible. The consequence might be a reduction in alignment quality.

7.3.3 Peat excavation

Excavation is the safest option for taking a road across peat. With the excavation method all of the weak material on the road line are excavated out to expose a firm layer of sufficient bearing capacity to accommodate the new construction. Thereafter an embankment of appropriate thickness is constructed on the exposed firm layer to enable the design to be fulfilled with a minimum threat of settlement or shear failure.

Excavation is however only generally economically feasible for the shallower depths of peatlands where quantities can be expected to be relatively small. Experience in the Northern Periphery to date suggests that the economic limit for the excavation method normally lies somewhere between 3 and 4 metres. After that it will become increasingly more difficult to keep the peat excavation sides stable. Also in deeper bogs local pockets of peat can be left in place that can result in settlements in the finished embankment if they are left uncorrected.

When doing deep excavations adjacent structures may be adversely affected by the removal of side support if adequately protection is not available. Another aspect is that suitable areas for the disposal of excavated materials must be identified locally. Despite these apparent pitfalls excavation is still generally the preferred method for most engineers for high speed main roads.

7.3.3 Peat replacement

Replacement is generally considered to be one of the safest of the methods available today, in addition to avoidance and excavation, for road constructing over peat. The method essentially involves taking out the weak peat material from along the line of the new road and replacing it with a suitable fill material to form the foundation for the new embankment. All partner areas across the Northern Periphery employ peat replacement methods with generally similar construction practices.

Peat replacement is generally the preferred method of construction for high speed roads that cross peatlands. If constructed well the method should produce a serviceable embankment with minor settlement requiring minimal future maintenance. Great care has to be taken however to ensure that all of the peat material is removed from below the new embankment as any soft pockets that remain could give rise to differential settlement in the finished structure. When using soil replacement technique there might also be a problems with disposing of the excavated peat and keeping the cut slopes of peat stable. Peat replacement is generally limited to depths of 8m of peat.

7.3.4 Peat displacement

Peat displacement is, along with peat replacement, considered to be one of the safest of the methods available for constructing roads over peat. A number of related methods such as *progressive displacement*, *partial excavation* and *assisted displacement* are including in this category.

The standard replacement method normally used is '*progressive displacement*' or 'displacement' which has been carried out very successfully on many projects across the Northern Periphery and is acknowledged to produce good results. Essentially the displacement method involves the construction of a standard embankment up to the edge of the peatland and then an embankment drive across the peatland by end tipping normally aided by a surcharge (see Figure 34). Some practitioners advocate an additional surcharge, 'a raised end', at the point of the advancing embankment to maximize the local displacement weight but this is not always used.

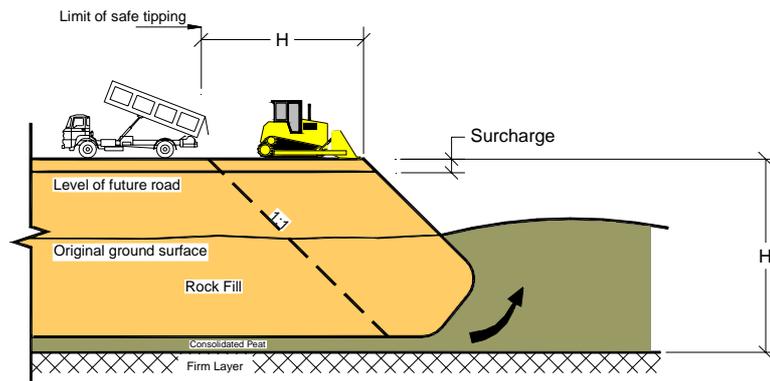


Figure 34. Long section through the progressive displacement method. (P. Carlsten modified by G. Smith)

The action of the combined weight of the embankment and surcharge causes a shear failure in the peat ahead of the embankment and this results in the affected peat being displaced laterally, i.e. the peat is pushed to the side by the nose of the advancing embankment. Within the peat displacement method there is derivative technique called '*partial excavation*', which differs from the main progressive displacement method in that it is assisted by excavating a manageable depth of peat in front of the nose of the embankment to reduce the amount of material to be displaced.

The main progressive displacement method is normally used where depth of peat to be replaced is beyond the economic limit of excavation and the weight of the intended road embankment is expected to be sufficient to displace the type of peat below.

The partial excavation method is normally used for the construction of wider embankments and under circumstances in where standard progressive displacement techniques may not be fully effective due to the need to place sufficient weight across the full cross-section to achieve uniform displacement. This method is particularly useful where the top layers of the peat deposit are very fibrous or woody and underlain by a more amorphous peat. This type of peat can act as a surface reinforcement to the peatland and resist the displacing forces induced by the imposed embankment.

On completion of the displacement the surcharge is left in place for a period (normally months) to aid the consolidation of any trapped pockets of peat and to ensure that the completed embankment has 'bedded down' before the final road construction layers are placed.

As with the replacement method, care has to be taken to avoid trapping pockets of peat below the embankment during the drive. Soil displacement is best used when it is known that the topography of the underlying hard layer can permit the embankment to move forward downhill without trapping pockets of peat. It is normal practice to take proving cores through the completed embankment after displacement to check if the displacement has been successful.

Displacement can be assisted by water jetting and blasting methods. Fibrous peat bogs can prove to be more resistant to the standard form of displacement due to their tendency to act as organic reinforcements against the method and they have on some occasions prevented the required shear taking place.

The reinforcement effect of the fibres can however be overcome by increasing the water content of the bog immediately ahead of the embankment by adding water to cause a reduction in the peat's shear strength to enable it to be displaced more easily. In this method jet lances are pushed into the base of the peat ahead of the embankment to increase the water content of the peat and slowly withdrawn whilst continuing to pump water to maximise the volume of peat treated.

Peat displacement can also be assisted through controlled blasting of the peat ahead of the advancing front. When the full displacement is completed the finished longitudinal edges can be 'blast assisted' to ensure that they are in firm contact with the hard strata below. There are essentially three ways in which blasting can assist displacement, namely trench shooting, toe shooting and underfill blasting, but there are many derivatives to these basic methods that use particular explosive charge patterns for specific end results.

In recent years other methods of embankment construction have proved more cost effective than blasting but the method still remains a useful tool for site specific applications. Where it has been used blast assisted displacement has normally only been possible in open areas that are free of structures and utilities apparatus where explosives can be used safely.

7.3.5 Peat left in place

This section summarizes those methods of road construction over peat, which rely on using the strength of the in-situ peat or seek to improve it into a material that can support the intended loads. The excavation, replacement and displacement methods previously discussed all rely on new materials being readily accessible to be imported into the work site to create an embankment through the peatland area. On projects with large scale earthworks this could involve importing very large quantities of new material, the possibility of difficult logistics and construction sequencing, with consequent results of high costs.

Methods that leave the peat in place and avoid the disadvantages of bulk earthworks are now becoming increasingly more attractive to engineers as road construction budgets reduce and more cost effective solutions are sought. As always any method chosen must satisfy the 2 main engineering considerations of stability and settlement but these are not impossible to satisfy even with the peat left in place. Stability can be improved by various means such as reducing the stresses in the foundation, increasing the strength of the underlying peat or by providing additional stabilising forces. Environmental and waste minimisation considerations are also adding to the arguments for methods that build on the peat in place.

Methods that leave the peat in place are therefore worth considering and this section will present a short review of 5 groups of techniques under the heading of 'Peat left in place' that utilise the underlying peat as a load bearing layer (Figure 35). More detailed information can be found in Roadex II phase II report "Dealing with Bearing Capacity Problems on Low Volume Roads Constructed on Peat", written by Munro (2004).

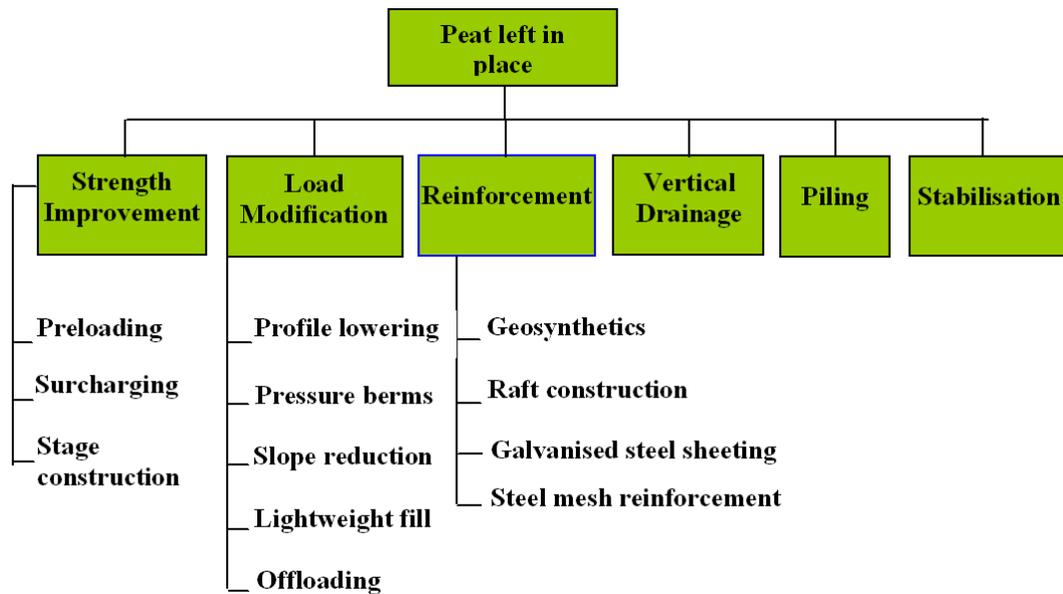


Figure 35. Methods that leave the peat in place.

Strength improvement

Strength improvement techniques include *preloading*, *surcharging* and *stage construction*. The principle of the *preloading* method is relatively simple. A load in excess of what is required is placed on the peat and allowed to settle until it reaches the predicted in-service settlement for the intended load (Figure 36). This can be done with or without the assistance of additional drainage. Once this settlement has been reached the excess load is removed and the service load left on the strengthened foundation at its final in-service settlement.



Figure 36. The principle of the preloading method.

The amount of *surcharge* needed to achieve the increased rate of settlement is a function of a number of things such as the type and depth of peat, its moisture content, ground water levels, distribution of load, etc. Each installation will invariably be unique requiring a geotechnical assessment of stability, settlement and increase in strength but a general Swedish ‘rule of thumb’ normally aims for an unloaded in-service embankment weight of 80% of the surcharged embankment after taking buoyancy effects into consideration. This equates to a nominal 25% surcharge over the weight of the final embankment ignoring the effects of buoyancy over time.

It is of course extremely difficult to construct a 4, 3, or even a 2 metre high surcharged embankment on weak peat without causing a shear failure in the underlying peat. As a consequence of this all of the authorities that use the preloading technique generally apply their fill materials in steps employing a “*stage loading*” procedure to construct their embankments. This means that each layer of the embankment is only placed when a suitable gain in strength has been achieved in the peat below from the previous layer from consolidation such that it will be able to withstand the new layer without failure.

Considerable settlements can however be expected during the stage loading operations and these should be known and their effects understood with reasonable accuracy at the design stage so that they do not come as a shock to the Resident Engineering staff on site.

Preloading with a surcharge is generally considered to be the most economical method of road construction in the Northern Periphery despite ending up with the apparent disadvantage of a “floating” road. The method is usually restricted to thin embankments close to the natural ground and normally means a limit of embankment heights to around 2-3m above the adjacent peatland level. It is normal practice to form the surcharge loads from temporary stockpiles of construction materials planned for use elsewhere in the permanent works such as sub-base or roadbase materials. This effectively means that the surcharges are cost neutral in the overall costing of the project.

The time needed for strength improvement techniques can however extend the embankment construction time. Materials needed for preloading and surcharging may need to be brought on to site earlier than required and require double handling as a consequence. The strength improvement methods need a monitoring system for consolidation and settlement to ensure that the required settlements are being achieved.

Load modification

The second group of methods that leaves the peat in place below the new embankment is ‘load modification’. This group of methods is concerned with altering the load distribution of the proposed embankment to better suit the existing strength of the peat.

Profile lowering (Figure 37) essentially means that the designer of the road amends the route vertical alignment to suit the weak soil conditions and lowers the intended embankment height across the peatland to an acceptable level for the strength of the underlying peat (normally no more than 3m above the peatland level). Profile lowering may not be possible if bridge clearances or waterway areas are critical.

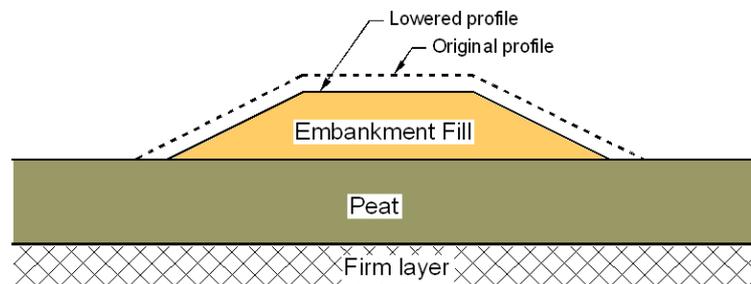


Figure 37. Cross-section through a profile lowering exercise. (P. Carlsten modified by G. Smith)

Stabilising berms, also known as ‘counterweight berms’ or ‘pressure berms’, are used to widen the base of an embankment, distribute the imposed embankment load over a greater surface area and increase the factor of safety of the main embankment against slip circle failure (Figure 38). As with all structures over peat stabilizing berms must firstly satisfy their own stability requirements and be loaded in a staged manner to remain in a stable condition at all times.

By widening the base of the embankment and providing a counterweight to the main embankment load the failure slip circle of the combined arrangement is forced deeper and longer into the peat foundation so improving the overall stability.

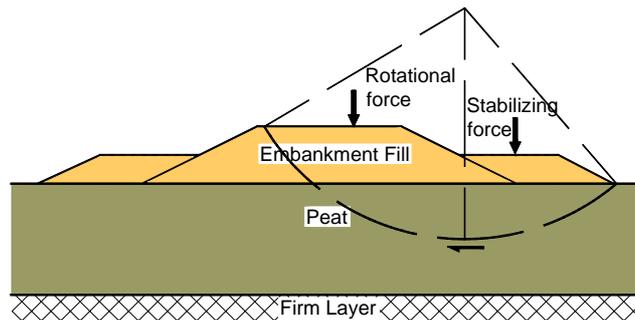


Figure 38. Cross-section showing the use of stabilising berms. (G. Smith)

Slope reduction is similar to the addition of pressure berms and is again intended to produce a wider embankment, a greater distribution of load over the foundation area and a longer more deep seated failure slip circle in the underlying peat. In this method the side slopes of the intended embankment are flattened to a shallower gradient to widen the overall width of the embankment on the peatland (Figure 39).

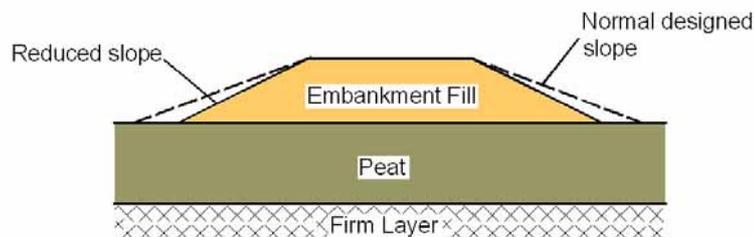


Figure 39. Cross-section through a slope reduction exercise. (P. Carlsten modified by G. Smith)

Stabilising berms and slope reduction methods require additional fill material and additional land for the wider construction. Low grade fill material (even peat) can be used as fill mass in berms. The methods also increase the overall weight of the embankment.

Lightweight fill (Figure 40) is primarily used to reduce the overall weight of an in-service embankment and thereby reduce the permanent stresses on the foundation. Embankments constructed with a lightweight fill core are normally installed in conjunction with a surcharge load to accelerate consolidation and settlement into the underlying peat and once the designed settlement has been reached the surcharge is removed leaving the finished in-service embankment on a strengthened subgrade.



Figure 40. Cross-section through a lightweight fill installation. (G. Smith)

Lightweight fills are normally only used as part replacements of embankments due to their cost and are generally restricted to those sections that cannot be economically addressed by other means. Typical lightweight materials currently being used in the Northern Periphery are listed in the report “Dealing with Bearing Capacity Problems on Low Volume Roads Constructed on Peat”, written by Munro (2004).

Offloading basically involves the removal of heavyweight material from an existing road construction and its replacement with something lighter (Figure 41). The aim of offloading is to produce a reduction in load on the underlying peat preferably to a level within its existing bearing capacity, ideally between 1/2 to 1/3 of the original.

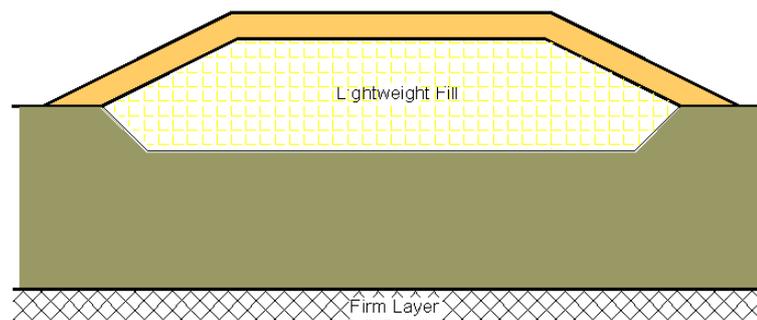


Figure 41. Illustration showing the ‘offloading’ principle. (P. Carlsten modified by G. Smith)

Both lightweight fill and offloading methods increases the costs of construction by the cost and transport of the specialised lightweight materials. Specialist installation design and placing of materials are also needed. Environmental considerations particularly with groundwater should be noted.

Reinforcement

Embankments can be reinforced by a number of materials each governed by their own particular technologies. The area of embankment reinforcement is probably one of the more dynamic areas of research in road construction and new manufacturers and new materials regularly appear in the technical press.

In the report “Dealing with Bearing Capacity Problems on Low Volume Roads Constructed on Peat”, written by Munro (2004), five areas of embankment strengthening are considered:

- Geotextiles and geogrids
- Timber raft construction
- Concrete raft construction
- Galvanised steel sheeting
- Steel mesh reinforcement of pavement layers

A great deal of discussion has centred around *geotextiles* and their application to the two types of road construction over soft ground, i.e. the 'thin' construction of roads and pavements and the 'thicker' construction of embankments. For thin fills the geotextile will act as a separator and filter, and the particular material should be chosen with these properties in mind. In the case of thicker fills the geotextile or geogrid will perform more of its true reinforcement role and a suitable grade of material will require to be selected. In this case it will be necessary for the designer to establish that there will be sufficient friction generated between the reinforcement and fill and underlying soil to resist the forces created.

The installation of a geotextile or geogrid does not affect the long term consolidation settlement of an embankment or its overall factor of safety but it does have some appreciable short and medium term benefits. In particular it has the advantage of assisting the local stability of the embankment during the construction phase by decreasing the rate of spread of the fill material on the surface until the foundation soil is strong enough to support the load itself. The geotextile/geogrid should however only be considered as a temporary supplement to the strength of the foundation soil to allow time for the soil to gain sufficient strength to support the embankment in the long term.

Timber raft construction is the oldest method of strengthening embankments over peat. The technology has been around for many years and involves laying an interlocking platform of reinforcing materials on the peatland surface to support and distribute the loads of the new embankment until such time as the underlying peat can gain sufficient strength to support the embankment on its own.

Timber grillages are currently not so popular as geotextiles or geogrids due to their high labour input and cost of timber but their inherent stiffness can provide better load distribution properties than high strength geotextiles.

Reinforced *concrete rafts* or slabs were used very successfully in Scotland and Ireland from the 1920's through to the 1950's. They were generally built in a series of slabs 200mm thick, doubly reinforced with edge strengthening and were either constructed directly on to the peatland surface or on top of a regulating layer of sub-base material. They were stiff structures, much more so than other strengthening systems such as mattresses, geosynthetics or grillages and needed minimum road construction layers to distribute the traffic loads.

A recent development in rafted embankment construction over peatland is the use of box profile *galvanised steel sheeting* as the reinforcing element. Installations of this method in the Partner areas to date have been confined to forest haul roads in Finland and Russia but their results appear promising enough to warrant trials on low volume public roads. These installations (since 1986) have used "Geoprofile" sheeting manufactured by Rautaruukki Oy of Oulu.

The reinforcement of pavement layers using *steel fabric mesh* is now a well established science following research carried out under the EU REFLEX project ("Reinforcement of Flexible Road Structures with Steel Fabrics to Prolong Service Life"). REFLEX started in March 1999 and lasted until August 2002 with the objective of developing technologies for road reconstruction and rehabilitation using steel reinforcement to improve 'whole life' costs of roads and extend the working life of road pavements.

Prior to the project it was expected that the use of steel meshes could increase the bearing capacity of the pavement but this was not borne out by the research. REFLEX did however show that the use of meshes could improve the service life of a road and reduce maintenance and rehabilitation costs over whole life.

Vertical drainage

The primary function of vertical drainage is to shorten drainage paths in a soil in order to cause an acceleration of the primary consolidation process and consequently a gain in strength. The process usually consists of a grid of drainage elements driven vertically into the soil by a mandrel, which is thereafter retracted leaving the vertical drain in place.

Vertical drainage is not generally used on peat unless it is seen to be contaminated or layered with less permeable soils such that it would benefit from the reduction in drainage paths. In the event of vertical drainage measures being considered necessary for whatever reason a detailed understanding of the local drainage regime, peat geomorphology and characteristics will be required before proceeding.

Piling

Piling is not normally used for road construction over peat unless settlement control is particularly critical. The method has high mobilizing costs, setting up and driving costs and generally only comes into its own in bridge approaches and the like where settlement criteria are normally more onerous.

Mass stabilisation

Mass stabilisation is a relatively new technique in road construction over peat and to date only the partner districts of Finland and Sweden have trialled the method within the Northern Periphery. So far the method has been used as a means to increase the strength of the underlying soil in order to improve its bearing capacity and increase the stability of the new embankment but the method also has the secondary benefit of reducing settlement time and horizontal displacements but these have not yet been fully explored.

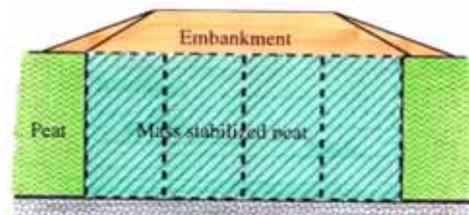


Figure 42. Cross section through stabilized peat. (Source: N. Jelisc, Mass stabilization of peat in road and railway structures.)

The philosophy behind mass stabilisation is relatively simple. The weak peat mass is mixed with together a binding agent, usually cementitious, by a mechanical mixing tool to produce a stronger and stiffer stabilised block (Figure 42). During the process a dry binder is fed to the mixing head with compressed air and the mixer rotated vertically and horizontally through the peat mass. Here the binder reacts chemically with the pore water in the peat and cures to a cementitious mass.

7.4 Discussion and summary

All of the techniques presented were discussed across the partner districts during the Roadex project to find out their current distribution and usage. It was found that not all of the techniques were currently being practised across the Northern Periphery but most had been trialled and tested by one or more partners at some time and local practices subsequently developed based on their experiences. Techniques can be listed by their usage in the three groups as shown in Table 4.

Table 4. The range of techniques presently available to the road construction over peat.

Method	Derivative	Accepted Practice	Developing Technique	Out of use Method
Peat excavation		✓		
Peat replacement		✓		
Peat displacement	Progressive displacement	✓		
	Partial displacement	✓		
	Assisted displacement			✓
Peat left in place	Preloading	✓		
	Surcharging	✓		
	Stage construction	✓		
	Profile lowering	✓		
	Pressure berms	✓		
	Slope reduction	✓		
	Lightweight fill	✓		
	Offloading	✓		
	Geosynthetics		✓	
	Timber raft			✓
	Concrete raft			✓
Vertical drainage			✓	
Piling		✓		
Mass Stabilisation			✓	

The original report concludes with an appendix of a 'Table of Improvement Methods' that summarises the advantages, disadvantages, risks and relative costs of the different methods of construction discussed.

All partner road districts have a common philosophy of applying low risk, standard techniques, such as soil replacement and soil displacement, to the construction of main national routes and restricting the use of the less developed newer techniques such as soil improvement, geotextiles, etc, to the lower classes of regional and district roads. The proven soil improvement techniques such as preloading were additionally considered acceptable where it could be shown that the necessary period of construction could be made available on site to allow time for the technique to produce the required soil improvement.

Most engineers approached during the course of the project were aware of the range of techniques available for the construction of roads over peat but most had their own preferences of 2 or 3 alternatives that they tended to use regularly. All of those questioned however

indicated that they would be prepared to use the more innovative techniques where they could be shown to be appropriate or cost effective for their particular sites.

The road maintenance schemes visited during the project were usually tackled empirically without the assistance of a detailed ground investigation. The 'offloading' technique was an exception to this and required a basic geotechnical input.

The choice of technique for a particular location was generally determined through a combination of the cost influencing factors:

- the complexity of the particular engineering works;
- the amount of soils investigation and testing necessary for each method;
- the required time for execution of the method;
- the type of budgetary control in force, e.g. rate of return, number of financial years, etc.;
- the amount of traffic disruption and additional traffic control required by the works;
- the expected future maintenance liability.

It was only after all of these construction and maintenance effects were examined that the most cost effective solutions emerged and final choice was made.

References

Hartlén, J. and Wolski, W. (eds), 1996. Embankments on Organic Soils. Elsevier Science Ltd , New York.

Munro, R., 2004. Dealing with Bearing Capacity Problems on Low Volume Roads Constructed on Peat. Roadex II report. www.roadex.org



8 Summary

This report summarizes the most promising structural solutions and techniques reported in different subprojects in Phase II of the Roadex II project. These solutions are specially customized for dealing with the typical road condition problems that can arise in the rural public, private and forest roads in the Northern Periphery. The report describes a basic procedure that should be followed when improving the condition of the low volume road network.

The first step when planning to improve the condition of the road network is to collect reliable information describing the road condition and causes behind the failures. The second step is to identify the problem roads sections by using the collected data. The integrated survey analysis should also be used in the third step which is the diagnosis of the problems. This report presents the basic principles of the road analysis techniques as well as new road testing and laboratory testing techniques, which have proven to work well in these investigations. These techniques include, for example, the use of Dynamic Cone Penetrometer (DCP), Ground Penetrating Radar (GPR), Falling Weight Deflectometer (FWD), GPS and digital videos. However, the importance of taking good quality laboratory samples and performing special material tests is also emphasized.

The second part of the report focuses on the most critical problem affecting the condition of low volume roads, the drainage. The report describes the typical drainage problems in the NP-area and gives different proposals for improving the problems. Results of life cycle cost analyses (LCA) done in Roadex project demonstrate clearly the great economic benefits of a good working drainage system. These LCA results show that drainage improvement, in practice, is always economic and if the pavement lifetime, for instance, can be doubled it is economical to clean the ditches even every second year if need be. Keeping the water away from the road surface and road structures should always have the highest priority in maintenance actions.

The third part of the report focuses on another major problem identified on the low volume road network in the NP area, permanent deformation. The report classifies the types of rutting caused by permanent deformation and also reports ways in which to evaluate the likelihood of excessive permanent deformation. Through the use of the new field test and laboratory test methods and their analysis results as well as the new models described in the report it is possible to assess the condition of existing pavements. The report also publishes a new tentative method description for strengthening design of low volume public, private and forest road pavement structures.

If the problems are related to the poor quality unbound materials in the top part of the pavement structures, as is often the case in NP areas, a promising option for road strengthening is treatment of this problem quality material. In the fourth part of the report both traditional and non-traditional treatment techniques are discussed. The test results conclude that different types of treatment agents should be used for different types of unbound aggregates and soil materials. However there is still much research to be done before the non-traditional treatment agents and methods can be utilised in a controlled manner.

Long and cold winters with frost action and freeze-thaw cycles and especially spring thaw weakening problems cause major problems for road engineers who are trying to maintain the road condition at an acceptable service level. The fifth part of the report focuses on structural solutions that have been found to perform well against spring thaw problems. As basic information for selecting optimum repair solution, a new classification for spring thaw weakening sites is presented. Based on this classification, several structural solutions and related construction techniques are presented along with their life cycle costs.

Peat is a common and special soil found throughout the NP area. The construction of roads over peat areas presents great challenges to the road builder not only in terms of the landscapes and terrain that have to be crossed but also in terms of the management of the engineering properties of peat, especially its high water content, high compressibility and low strength. A short review of the engineering properties as well as the general aspects of structural solutions presently available to practising road construction on peat are presented in the sixth part of the report.

Rural roads in the Northern Periphery area do not, in most cases, have only a single reason for their problems and it is also important to understand the combined effect of several different factors, including loading by heavy vehicles. In order to produce sustainable and cost effective repair solutions, each problem section requires good survey data, correct diagnosis and careful design before the selection and execution of the rehabilitation structure. Also the needs of the road users should always be kept in mind when selecting the measures, locations and timing of road condition improvements.

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



Copyright © 2005 Roadex II Northern Periphery. All rights reserved.

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

