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SUMMARY OF DRAINAGE ANALYSIS IN REGION NORD, NORWAY

Demonstration Project Report

ABSTRACT

Drainage is one of the most important factors to be kept in mind in road design and maintenance projects. It is accepted generally that road structures work well and last longer in dry conditions. Researches have shown that that poor drainage is often the main cause of road damages and problems with long term road serviceability. This knowledge however has not always been applied in practice with the result that the general drainage condition of the road networks is not good. Previous ROADEX projects have reported that poor drainage is the one of the biggest problems for Northern European rural roads, and parts of the main road network. Drainage improvement, and maintaining the drainage in a good condition has therefore a major effect in reducing the rate of deterioration of roads and ROADEX research has shown that drainage improvement measures can increase pavement lifetimes by 1.5-2.0 times. Drainage measures are thus very profitable and offer major savings in annual paving costs.

A drainage analysis methodology has been developed in the ROADEX project to locate those critical road sections needing drainage improvement and regular maintenance. In the analysis, data is collected from all of the important factors that affect the road drainage condition. After this data has been analysed, classified and reported, the critical road sections can be awarded a special drainage maintenance class for use in maintenance contracts. Drainage analysis can be carried out on both paved and gravel road networks. The survey results are reliable and repeatable and allow the current drainage condition of the road network to be monitored.

Demonstrations of the ROADEX drainage analysis in northern part of Norway were carried out on selected sections of four paved roads and on two gravel roads. The total length of the roads analyzed was approximately 185 kilometres.

During the surveys the drainage condition was found to vary considerably across the roads surveyed. Overall the drainage was found to be in mainly good condition, but sections of extremely poor condition were also detected. Typically the poor drainage was related to side sloping road profiles, washout damages, verges and access road culverts. Significant variations in elevation were present within the sections and these had a great effect on the local drainage circumstances. In general the project showed that the ROADEX drainage analysis can be applied to the road network in Norway.

Laser scanner data was also collected during the drainage surveys to enable the depth of the ditches to be calculated for some selected sections, and to monitor the pavement surface and shape of the road cross section. These tests showed that laser scanner data can be very useful in drainage evaluation.

KEYWORDS

Drainage, analysis, verge, pavement, life time, rutting, IRI, laser scanner

PREFACE

In the beginning of May 2011 Roadscanners Oy carried out a series of drainage analysis field surveys in northern part of Norway (Region Nord). The goal was to demonstrate the ROADEX drainage analysis technique and guidelines on the Norwegian road network.

The field measurements were carried out by Seppo Tuisku of Roadscanners Oy with the help of the Norwegian Public Roads Administration (Statens Vegvesen). Harald Kristensen of the Region Nord office assisted in the field surveys.

The processing and analysis of the measured data was carried out by Seppo Tuisku with the help of Sami Tuisku. This report was jointly written by Seppo Tuisku and Annele Matintupa. Timo Saarenpää and Pekka Maijala from Roadscanners Oy helped with the handling of the IRI and rutting data supplied by the client. Timo Saarenketo steered the demonstrations as lead manager of the ROADEX D1 “Drainage Maintenance Guidelines” group. Ron Munro helped with the demonstration arrangements and also checked the language. Mika Pyhähuhta from Laboratorio Uleåborg designed the report layout.

All of the work carried out in the project was made in close cooperation with personnel from the Norwegian Public Roads Administration. Without their help and support it would not have been possible to complete the work. The authors would specially like to thank and acknowledge the assistance given by Per Otto Aursand of Statens Vegvesen.

Finally the authors would like to thank the ROADEX IV Project Steering Committee for their guidance and encouragement in the work.

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CONTENTS

1. INTRODUCTION

1.1 THE ROADEX PROJECT

The ROADEX Project is a technical co-operation between road organisations across northern Europe that aims to share road related information and research between the partners. The project was started in 1998 as a 3 year pilot co-operation between the districts of Finland Lapland, Troms County of Norway, the Northern Region of Sweden and The Highland Council of Scotland and was subsequently followed and extended with a second project, ROADEX II, from 2002 to 2005, a third, ROADEX III from 2006 to 2007 and a fourth, ROADEX IV from 2009 to 2012.

Figure 1: The Northern Periphery Area and ROADEX IV partners.

The Partners in ROADEX IV "Implementing Accessibility" comprised public road administrations and forestry organisations from across the European Northern Periphery. These were The Highland Council, Forestry Commission Scotland and Comhairle Nan Eilean Siar from Scotland, The Northern Region of The Norwegian Public Roads Administration, The Northern Region of The Swedish Transport Administration and the Swedish Forest Agency, The Centre of Economic Development, Transport and the Environment of Finland, The Government of Greenland, The Icelandic Public Road Administration and The National Roads Authority and The Department of Transport of Ireland.

The aim of the Project was to implement the road technologies developed by ROADEX on to the Partner road networks to improve operational efficiency and save money. The lead partner for the project was The Swedish Transport Administration and the main project consultant was Roadscanners Oy of Finland.

A main part of the Project was a programme of 23 demonstration projects showcasing the ROADEX methods in the Local Partner areas supported by a new pan-regional "ROADEX

Consultancy Service" and "Knowledge Centre". Three research tasks were pursued as part of the project: "Climate change and its consequences on the maintenance of low volume roads", "Road Widening" and "Vibration in vehicles and humans due to road condition".

All ROADEX reports are available on the ROADEX website at www.ROADEX.org.

1.2 THE DEMONSTRATION PROJECTS

Twenty three demonstration projects were planned within the ROADEX IV project. Their goal was to take selected technologies developed by ROADEX out on to the local road networks to have them physically used in practice to show what they could achieve. The projects were funded locally by the local Partners, designed and supervised by local staff, and supported by experts from the ROADEX consultancy.

The demonstrations were managed in 6 groups by a nominated lead manager from ROADEX:

D1 - "Drainage Maintenance Guidelines"

D2 - "Road friendly vehicles and Tyre Pressure Control"

D3 - "Forest Road policies"

D4 - "Rutting, from theory to practice"

D5 - "Roads on Peat"

D6 - "Health and Vibration"

This report deals with the demonstrations project in the D1 "Drainage Maintenance Guidelines" group carried out in the Region Nord, Norway.

2. ROADS SURVEYED

The drainage analysis surveys of this report were carried out on selected sections of roads E6, Fv17, FV78, Rv73, Fv213 and Fv254 in Region Nord, Norway. The sections of roads surveyed are shown on the map in Figure 2 and detailed section information is presented in Table 1.

- Road E6 was surveyed from section 2 to section 12. The survey started from Trofors and ended 6 kilometres northeast from Mo I Rana. Field work in section 2 was divided into two parts because of the length of the section.

- Three sections were surveyed on road Fv17. The survey started from a snow gate after the Helgelandsbrua Bridge (section 25 chainage 15630m) and the end point was about 100 metres after the intersection of the road E12 (section 34 chainage 31000m).

- One section was surveyed on road Fv 78. The survey started from the road E6 at Dalenget to the bridge over river Drevjo.

- Two sections were surveyed on road Rv73. The surveys started from the beginning of section 3 to chainage 5500m of section 4. The reason for finishing the survey in the middle of the section 4 was the increasing amount of snow in the ditches.

- Two gravel road sections were also surveyed to test the drainage analysis on gravel roads on the Norwegian road network. The selected sections were on roads Fv213 and Fv254. The total length of surveyed gravel roads was about 12km.

Table 1. The surveyed road sections and their lengths.

Road	Section	From	To	Length [m]
Paved Roads				
E6	2	0	37779	37779
E6	3	0	6634	6634
E6	6	0	9984	9984
E6	7	0	4986	4986
E6	8	0	12113	12113
E6	9	0	6487	6487
E6	10	0	2885	2885
E6	12	0	6000	6000
Fv 17	25	15630	26708	11078
Fv 17	30	0	15486	15486
Fv 17	34	100	31000	30900
Fv78	1	0	11886	11886
Rv73	3	0	11375	11375
Rv73	4	0	5500	5500
				173093
Gravel Roads				
Fv213	1	0	3600	3600
Fv254	1	0	8425	8425
				12025
Total				**185118**

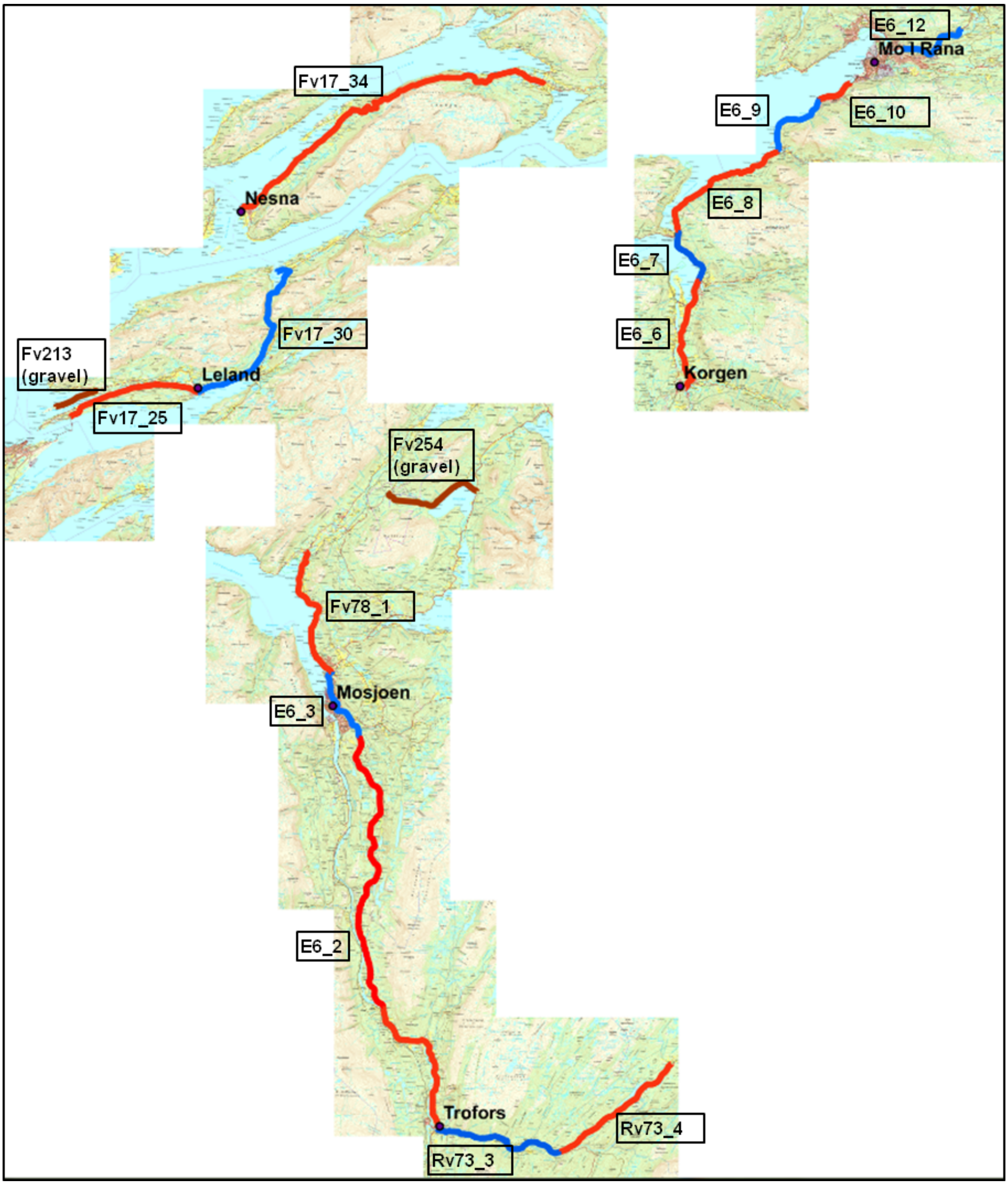

Figure 2: Surveyed roads in Region Nord area in Norway.

The E6 is one of the main roads in Norway and traffic was busy within the surveyed chainages. The Fv17, Fv78 and Rv73 were all fairly busy roads. The gravel roads Fv213 and Fv254 had noticeably less traffic. Elevation changes were large on a large part of the surveyed roads. Many of the sections were located on coastal terrain and some sections were on river valleys which resulted in the road cross profile to be mostly side sloping.

3. DATA COLLECTION, FIELD SURVEYS

3.1. GENERAL

The data collection for the demonstration project was carried out in May 2011. The sections for the survey were selected by the Norwegian Public Roads Administration (NPRA). The surveys started from Mosjoen area. The first surveyed sections were south from Mosjoen on road E6 and on road Rv73 which was surveyed eastbound from Trofors. The original plan also included the road Fv 292 which is about 50 kilometres east from Trofors but because of snow this was not possible to be analyzed. The survey on road Rv73 had to be discontinued before the end of the section 4 for the same reason.

The drainage survey then continued north from Mosjoen on the roads Fv78 and E6. The gravel road Fv254 was also surveyed on the way towards Mo i Rana.

The last sections in the drainage survey were located southwest from Mo i Rana on road Fv17 where three sections were surveyed. Gravel road Fv213 was also surveyed at that time.

As shown in Table 1 the total length of surveyed roads was about 185 kilometres. Paved roads covered about 173 kilometres of the surveyed chainage and the remaining 12 kilometres were on two separate gravel roads.

The weather during the survey days was dry and most of the time it was sunny. Only during the last surveyed sections on road Fv17 did it become cloudier but it did not rain.

3.2. VIDEO AND GPS

Drainage analysis in the field was carried out on one road section at a time and both sides of the road were analysed separately. The vehicle used in the survey was provided by Roadscanners Oy and is shown in Figure 3. The driving speed during the data collection was about 30 km/h. The van was driven close to the road shoulder so that the video cameras had the best possible view of the ditch and roadside. An APD Communications INCA 2 GPS device was used for GPS positioning. All data was linked to GPS coordinates using Road Doctor™ CamLink software.

Two digital video cameras were used in the survey. One camera was used to record the road view, and the other camera to record the ditch.

Figure 3: The survey vehicle used in the project. Video cameras were placed in the orange CamLink box for shelter from the rain and dust.

A laptop equipped with Road Doctor™ CamLink software was used to record the video data from the cameras and the classification of the drainage. Preliminary classifications were directly recorded in the vehicle using the car-pc keyboard. Audio comments were also recorded to assist data interpretation in the office. These audio comments were mainly about soil type, presence of ditches and their condition, and to correct any mistakes in classifications made with the keyboard (Figure 4).

Figure 4: Keyboard (front) was used for drainage analysis, pieces of paper helped to choose the right keys during the survey. Laptop (back) was used to collect the laser scanner data.

The preliminary analysis in the field was adjusted later in the office. This was made with the help of data from the road camera, and supplemented by data from the ditch camera view which was very useful in having a closer record of the ditches.

3.3. LASER SCANNER

In recent years the greatest developments in all of the NDT techniques used in road surveys have been made with laser scanners and it is a fact that these systems will fast become a standard tool for a variety of tasks in road condition management.

Laser scanning is a technique where the distance measurement is calculated from the travel time of a laser beam from the laser scanner to the target and back. When the laser beam angle is known and beams are sent out to different directions from a moving vehicle with known position, it is possible to make a 3d surface image, a “point cloud”, from the road and its surroundings. In the point cloud with millions of points, every point has an x, y and z coordinate and a number of reflection or emission characteristics.

The accuracy of the laser scanner survey can be reduced by different factors reducing visibility, such as dust, rain, fog or snow. Also high vegetation can prevent information being obtained from the actual ground surface.

A laser scanner is composed of three parts, the laser canon, a scanner and a detector. The laser canon produces the laser beam, the scanner circulates the laser beam and the detector measures the reflected signal and defines the distance to the target. The distance measurement is based on the travel time of light, or phase shift, or a combination of both.

The quality and price of mobile laser scanner survey systems vary but they can be roughly classified into two categories a) highly effective high accuracy systems and b) cheaper “everyman´s” laser scanner system that have reduced distance measurement capability and accuracy.

Laser scanner results can be used in several different ways in low volume road surveys. A road cross section profile can provide good information on the shape of the rutting and if there are verges preventing water flow away from the pavement. A map presenting surface levels in colour codes can be prepared to identify the places with debris filled ditches and clogged culverts. The changes in width of the road can also be easily seen from the maps. When other road survey data is combined with laser scanner data it can provide excellent basic information for analyzing permanent deformation and road diagnostics.

In this project the data collection was collected using a SICK LMS151 laser scanner mounted on a survey van as shown in Figures 3 and *5.* The analysis was made with the new Road Doctor Laser Scanner module (RDLS) of Road Doctor software. This module facilitates integrated analysis of the laser scanner data together with other road survey data.

Figure 5: The laser scanner behind the survey vehicle at the height of 3m.

4. DRAINAGE ANALYSIS PRINCIPLES

4.1. GENERAL

Road drainage arrangements are quite similar across the Nordic countries. The main difference is the terrain. In Finland and in Sweden, where the ROADEX drainage analysis has been largely used in recent years, the terrain is much flatter compared to the project area in Region Nord, Norway.

Elevation changes in the surveyed road sections in Norway were significant which made the drainage conditions challenging. Most of the surveyed chainage was in coastal areas which meant that the road profile was largely side sloping. Side slopes were mainly steep and on the upper side there could be rock cuts and very little room for a ditch.

A typical drainage problem in these areas was that the drainage system on the upper side of the slope was not efficient enough. If the ditch in the upper side of the road is not in good condition, problems will most likely occur. Some cases the drainage system on the upper side was completely missing because there was no room for it, or soil or road material had filled the ditch. Another common problem in large elevation changes was erosion at the edge of the pavement.

4.2. DRAINAGE CLASSIFICATION

The drainage classification of the surveyed roads was carried out using the principles that will be presented in this chapter. A complete description of the ROADEX drainage analysis classification is given in the ROADEX report "*Drainage Survey Method Description*". A brief summary of the ROADEX drainage descriptions follows:

4.2.1. Drainage Class 1; Drainage in Good Condition

Drainage Class 1 means that the drainage condition is faultless. The cross-section of the road has preserved its form well and water flows unrestricted from the pavement to the ditch. Water has also a clear passage in the ditches. Examples of drainage Class 1 are presented in Figure 6.

Figure 6: Examples of road sections with drainage Class 1 in Region Nord in Norway.

4.2.2. Drainage Class 2; Drainage in Adequate Condition

In drainage Class 2 there can be some visible changes to the road cross-section. The road shoulder has narrow verges or vegetation growth that is preventing the free flow of surface water from the road surface into the ditch. There is some vegetation in the ditch that restricts water flow and creates damages. Some soil is sliding from the road side slope into the ditches and raising the bottom of the ditch. This hinders water flow and raises the ground water level. Examples of drainage Class 2 are presented in Figure 7.

Figure 7: Examples of road sections with drainage Class 2 in Region Nord in Norway.

4.2.3. Drainage Class 3; Drainage in Poor Condition

Drainage Class 3 covers those road sections with severe drainage problems. The road shoulder has a high verge and/or dense vegetation that are causing water ponding on the traffic lane or on the shoulder. Vegetation is growing in the ditches and preventing the water flow and creating dams in the ditches. Soil is flowing from ditch slopes into the bottoms of ditches and blocking the flow of water. Clogged culverts or outlet ditches are preventing the water flow in the ditch. All of these situations lead to the development of deformation and damage in the road cross-section. Examples of drainage Class 3 are presented in Figure 8.

Figure 8: Examples of road sections with drainage Class 3 in Region Nord in Norway.

4.3. VERGE CLASSIFICATION

In this ROADEX drainage demonstration project in Region Nord Norway verges were classified into two classes: “no verges” and “verges exist”. A brief summary of the ROADEX verge descriptions follows:

4.3.1. Verge Class 1; No verges

Class 1 verges cover those road sections where there is no verge and water can flow freely from road surface. Figure 9 presents two examples of verge Class 1 road sections.

Figure 9: Two examples of verge Class 1, i.e. road sections without verges.

4.3.2. Verge Class 2; Verges Exist

Class 2 (verges exist) cover all road sections with verges. The height of verges can vary from low verges, which only have a minor effect to drainage, to high ones which clearly prevent surface water flowing away from road surface. Examples of verge Class 2 are presented in Figure 10.

Figure 10: Examples of verge Class 2, roads with a verge. The effect of verges on the workings of the road drainage system varies greatly in different circumstances.

4.4. LASER SCANNER

Laser scanner surveys in drainage analyses have been previously tested by the ROADEX projects in Umeå Södra area in Sweden and in the Western Isles of Scotland with promising results. The survey in Region Nord was the third ROADEX drainage demonstration survey to include a laser scanner survey. The aim of the task was to measure the depths of the ditches.

The data from the laser scanner surveys was processed with the Road Doctor Laser Scanner module. According to the guidelines in the Nordic countries the bottom of the ditch should be more than 20-30 cm deeper than the bottom of the road structure. In this drainage analysis project a GPR survey was not carried out, so the bottom of the road structure could not be determined.

On the surveyed gravel roads Fv213 and Fv254 the bottom of the road structure was assumed to be about 50cm deep. On road E6 section 12, the test section for ditch depth calculation, two structure thicknesses were considered (50cm and 80cm). When the structure thickness is 50cm the depth of the ditch should be at least 80cm. Norwegian main roads usually have a structural thickness of 80cm, which means that ditch bottom level should be 110cm from the road surface.

4.4.1. Ditch Depth Analysis

The depth of ditches was obtained from the Road Doctor Laser Scanner software module. Five points were selected from the road cross section; the level of both ditch bottoms, the level of both road edges and the level of the centreline (Figure 11). With these points selected by the program it is possible to calculate the bottom of the ditch and add the ditch depth information to the analysis view.

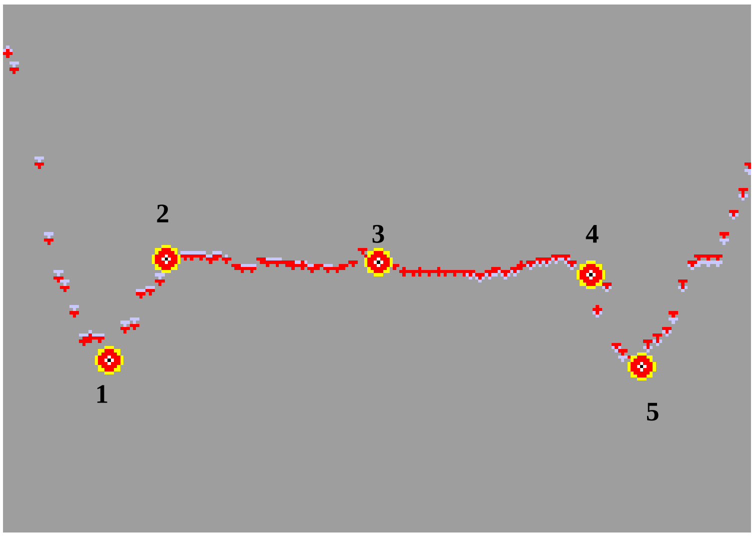

Figure 11: Diagram showing the points selected from the cross-section, from left to right: 1.The bottom of the left ditch 2.Left road edge 3.Centereline 4.Right road edge 5.The bottom of the right ditch

4.4.2. Road Surface Analysis

Deviations on a road surface can be easily detected from a “rainbow map” made from laser scanner data. Such changes in the topography of a pavement surface, when compared to the normal shape, can indicate those areas suffering deformation or frost problems in the road. Usually these deviations in the road surface are not easy to identify visually. The use of the rainbow map makes it considerably easier to visualize these deviations. Rainbow maps show road surface topography and its deviations and damages. The road centreline is captured as the zero level. Each complete colour palette represents a 40mm change in surface level relative to the centreline. With the help of a rainbow map the changes in the road crossfall can be critically examined. Figure 12 shows a road section with an area of uneven frost heave caused by a clogged exit road culvert. This can be seen in the map from chainage 5050m to 5085m. Cracks are formed in sections where the rainbow lines are not straight and continuous (Figure 12).

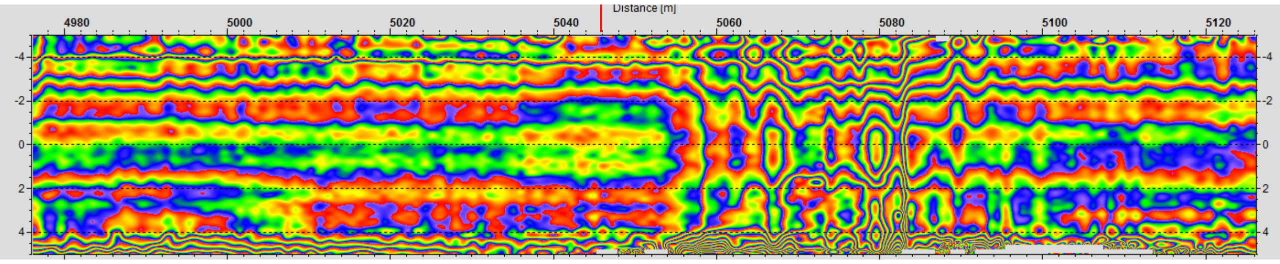

Figure 12: Surface rainbow map of road section chainage 5050m to 5085m.

5. RESULTS OF THE DRAINAGE ANALYSIS

The main observations of the surveyed road sections are summarised in the following pages under their respective headings.

5.1. ROAD E6

5.1.1. Road E6 Section 2

Section 2 of the road E6 was divided into two parts for field work as the length of the whole section was nearly 38 kilometres. The first part was from Trofors to Laksforsen, a length of 12905m, and the second part was 24874m, ending at the road register plate close to the Olderskog junction.

At the beginning of the first part there were many drainage problems. mostly in side sloping road profiles on the upper side of the slope (Figures 13, 14, 15 and 16). In some cases the ditch was totally blocked which forced the water to run along the edge of the pavement, or even on the pavement (Figures 17 and 18). As in the earlier ROADEX drainage analysis projects private access road culverts were problematic also in Norway. On this road section many of the private access road culverts were missing. Examples of defective access road culverts are shown in Figure 19. From 8400m onwards the drainage was in better condition but some side sloping sections still had insufficient ditches (Figure 20). Verges were blocking the water flow to the ditches at times (Figure 21). The last part of this section had been upgraded and it was in better condition.

Figure 13: Little room for ditches on the upper side of the slope, chainage left: 995m, right: 5720m

Figure 14: Drainage problems in a steep side sloping road profile, chainage left: 4530m, right: 4960m

Figure 15: Drainage problems in a steep side sloping road profile, chainage left: 5650m, right: 7070m

*

Figure 16: Water standing on the upper side of the slope, chainage left: 7370m, right: 34610m

Figure 17: Erosion damages, chainage left: 870m, right: 1465m

Figure 18: Erosion damages, chainage left: 1710m, right: 13635m

Figure 19: Examples of problems resulting mainly from private road access junctions and their culverts, chainages top left: 2250m, top right: 4300m, bottom left: 13495m. At chainage 32635m water is standing behind bus stop (bottom right).

Figure 20: Ineffective drainage on the upper side of the side sloping road profile, chainages top left: 12350m, top right: 29330m, bottom left: 35270m, bottom right: 37220m

Figure 21: Verge is blocking the water, chainage left: 15270m, right: 16200m

5.1.2. Road E6 Section 3

The third drainage section surveyed on road E6 was 6634m long and ended inside the Mosjoen town area where water outlets were in place. The drainage on this section was mostly working well, though some short sections in the side sloping road profile had minor drainage deficiencies. In the final part of the road there were some problematic sections where the drainage system was inadequate between the road and the cycle path. Examples of drainage condition from section 3 are shown in Figures 22 and 23.

Figure 22: Inadequate drainage on the upper side of the side sloping ground (chainage 1600m, 1840m)

Figure 23: No drainage system between the cycle path and the E6 road (chainage 5445m, 5910m)

5.1.3. Road E6 Section 6

Section 6 from Korgen to Bjerka was 9984m long and the drainage was mainly working well. In total 77.5% of the chainage was classified as drainage Class 1. The road profile was more variable in this section with 45% of the chainage classified as side sloping profile. This is far less than the average in this project.

Due to the instability of the soil, some ditch walls had collapsed into the ditch (Figure 24). If the ditches are going to be cleaned here, this soil might need some kind of protection against erosion.

Figure 24: Problems with instability of the soil, also a verge problem chainage left: 1370m, right 2470m

From chainage 6000m to 7000m on the left side the drainage system clearly needed improvement (Figures 25). The road profile varied inside the section but mostly it was side sloping from left to right.

Figure 25: Left: Standing water in the ditch at chainage 6750m, Right: Partly blocked culvert in a private access road junction at 6800m

Laser scanner surveys can show where the inner and outer slopes have kept their shape. Unstable material on the slopes can move on the slopes and fill the ditches, as could be seen from the laser scanner data. Figures 26-27 show laser scanner cross sections illustrating the differences in slope shape.

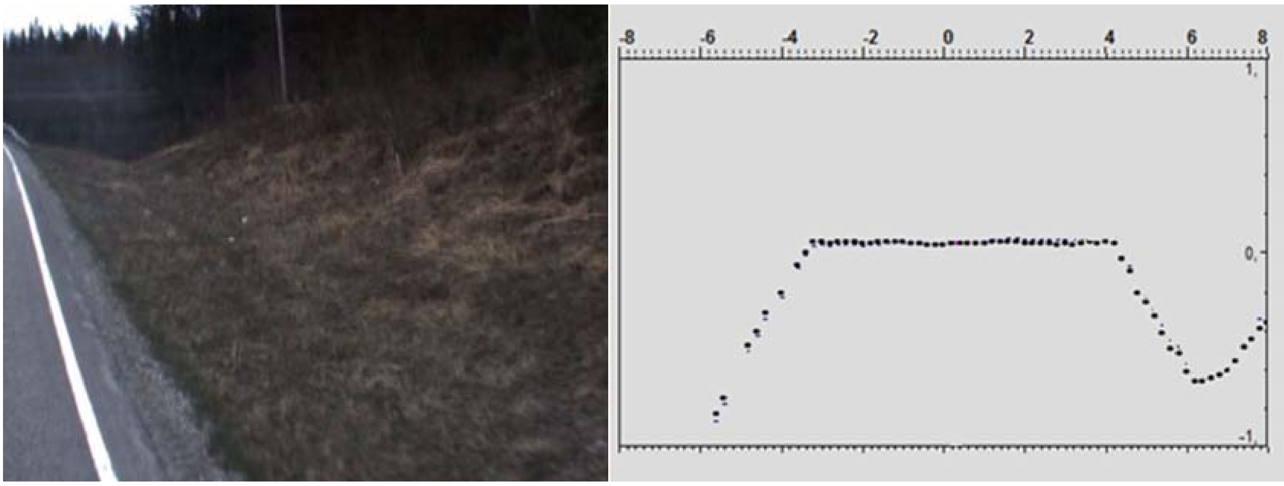

Figure 26: Example of a well working drainage, chainage 5210m.

Figures 27: Inner slopes of road have lost their shape and verges have been formed. The ditch depth is only 50cm, example at 5160m. Erosion can also be seen at the pavement edge.

5.1.4. Road E6 Section 7

The drainage in section 7 was mainly in good condition. In this section there were several rock cuttings. Most of them had good ditch depth although some had fallen stones in the bottom of the ditch (Figures 28). There were three tunnels within the section. The length of section 7 was 4986m.

Figures 28: Left: Stones in the bottom of the ditch at chainage 2180m. Right: Rock cutting with good ditch depth at 3500m.

5.1.5. Road E6 Section 8

Section eight was 12113m long and ran from Finneidfjord to Dalsgrenda. The road was located on the mountainside and because of this the road profile was mostly side sloping, and at times the slope was extremely steep.

At the beginning there were two tunnels and the drainage was working efficiently. Further on the road section there were several drainage defects on the upper side of the slope that were typical for the type of terrain (Figure 29). Sections in rock cuttings had problems (Figure 30), as did sections with verges (Figure 31).

Figure 29: Examples of erosion, Left: Shallow ditch filled with unstable material at chainage 5530. Unstable material has filled the ditch at 8560m.

Figure 30: Example of rock cutting near the road. Left: general perspective at chainage 10400m and Right: detailed photo of clogged ditch at chainage 10440m.


Figure 31: Examples of verge problems, Left: High verge at chainage 2970m, Right: Verge problem at 8130m chainage

A typical problem arising from slide sloping profiles is erosion. Water runs along the pavement or near the edge causing damages (Figure 32).


Figure 32: Examples of erosion damage; Right: Washout damage at chainage 2320m and Left: more detailed photo at chainage 2330m.

As mentioned in the previous chapter, poorly working private access road junctions were also seen to cause problems (Figure 33).

Figure 33: Private access road junction is blocking the water at chainage 4160m,

Near the end of the section a new bicycle path had been provided on the upper side of the side sloping road profile. This was located on a higher elevation than the road itself and the ditch between them was shallow. This was considered to be a potential problem over time if the ditch fails to keep the surface water off the road (Figure 34).

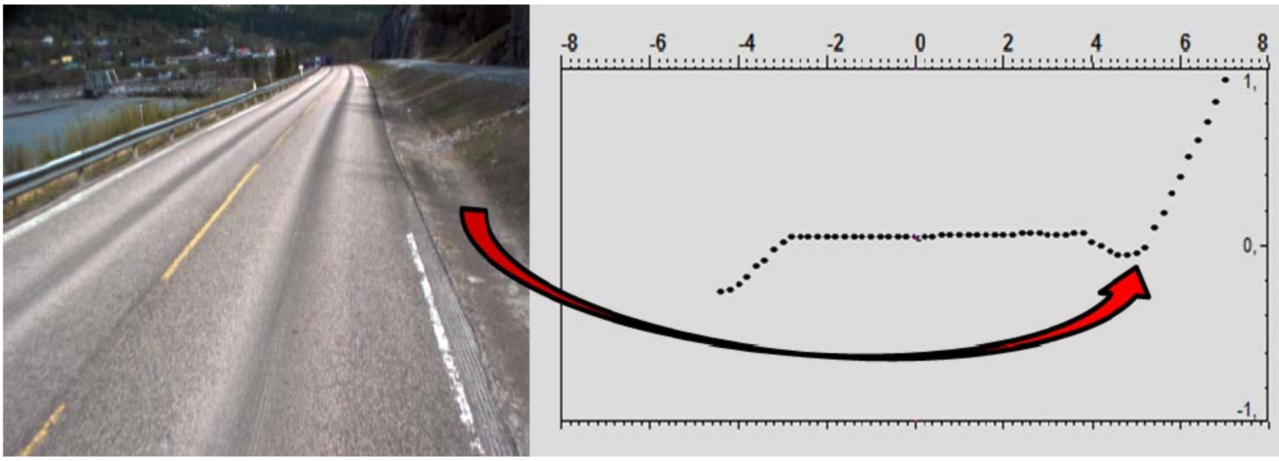

Figure 34: Shallow ditch between the road and the bicycle path. Laser scanner shows small deformations on the right side of the road.

5.1.6. Road E6 Section 9

The length of the section 9 from Dalsgrenda to Hauknes was 6487m. The road was in the mountain area and the road cross profile was mainly side sloping (80.5%). The drainage was generally in good condition but some short sections on the upper side of the slope had drainage deficiencies (Figure 35).

Figure 35: Partly blocked ditch on the upper side of the slope at chainage 5320m.

5.1.7. Road E6 Section 10

Section 10 was a short section, only 2885m in length. This section had several problematic sections again on the upper side of the road in side sloping road profile. Between the road and the bicycle path there was little, or in some cases no room at all, for a ditch (Figures 36-37).

Figure 36: Road damages because there is little room for ditches, chainage left: 1160m, right: 2110m

Figure 37: No ditches, chainage left: 2050m, right: 2530m

5.1.8. Road E6 Section 12

The final road section surveyed on road E6 commenced after the bridge over the River Ranelva in Selfors, north from the centre of Mo i Rana. The length of the section was 6 kilometres and nearly all of the chainage (95%) was on side sloping road profile. Several sections were identified with severe drainage deficiencies on the upper side of the slope (Figure 38).

Figure 38: Partly filled ditch blocks the water flow at chainage 240m. Right: No ditch at 550m chainage.

The severe drainage defects (Figures 39) on the section made it an interesting section in the statistical analysis. Unfortunately the profilometer data available had been surveyed in the lane along the increasing chainage, and in this road section this happened to be on the lower side of the slope. For this reason the available profilometer data did not correlate with the identified drainage deficiencies.

Figure 39: Severe drainage deficiencies, chainage left: 2500m, right: 5470m.

At the end of the section the inner slope had lost its shape. This had caused verge and erosion problems (Figure 40).

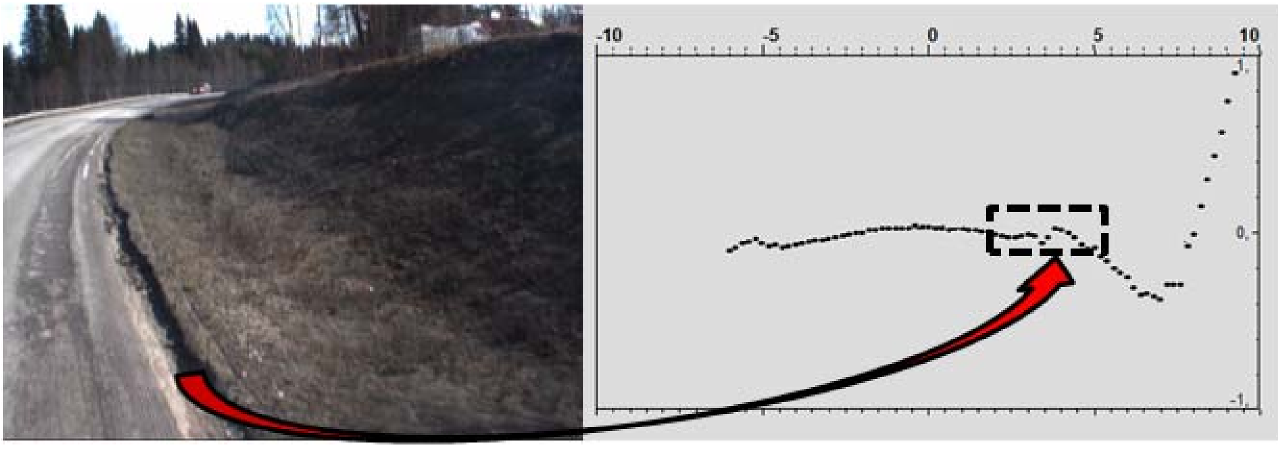

Figure 40: Erosion damage on the edge of the pavement at chainage 5840m

5.2. ROAD FV17

5.2.1. Road Fv17 Section 25

The survey on Section 25 of road Fv17 was started from the snow gate after the Helgelandsbrua Bridge (chainage 15630m). The length of the section was 11078m. The road profile was mainly side sloping (79%) and the drainage was in good condition. Nearly 86% of the chainage was classified as drainage Class 1. From chainage 18500m to 19000m there was a newly upgraded length in steep side sloping terrain. This section had water outlets and the ditch in the cutting had good shape and was deep enough (Figure 41).

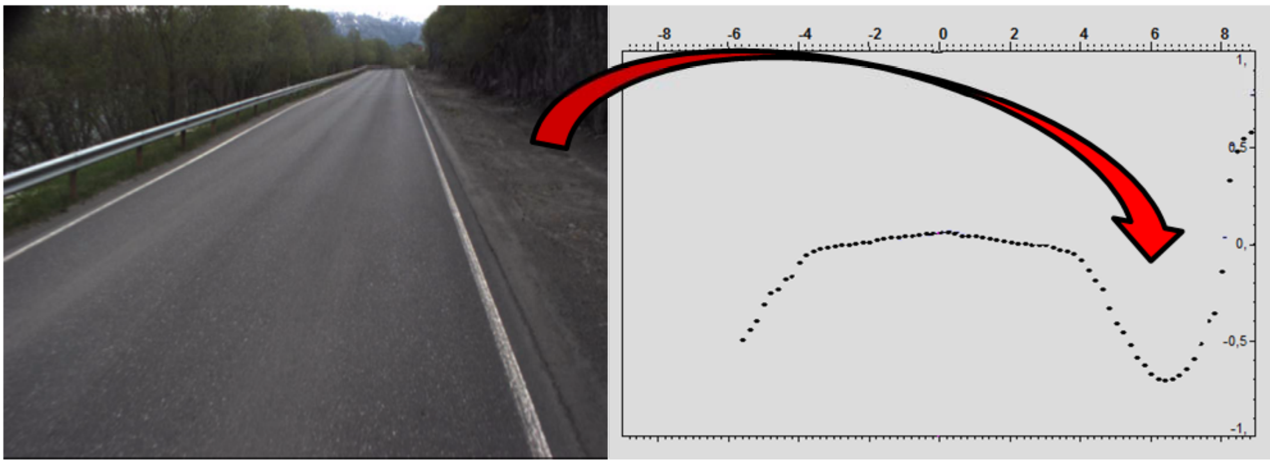

Figure 41: Upgraded drainage system (chainage 18600m)

There were however a couple of lengths that still needed drainage improvement. This was especially the case at the end of the section where vegetation growth was reducing the efficiency of the deep ditches. (Figures 42 and 43). High verges were also a problem in some sections (Figure 44).

Figure 42: Left: Shallow ditch in side sloping road profile at chainage 19280m. Right: No room for a ditch between the cutting and guardrail at 21690m

Figure 43: Vegetation was slowing down the water flow at chainage 25220m, good depth on the right ditch though. Laser scanner shows that the ditch on the left side is too shallow. Severe deformation problems can also be seen on the road.

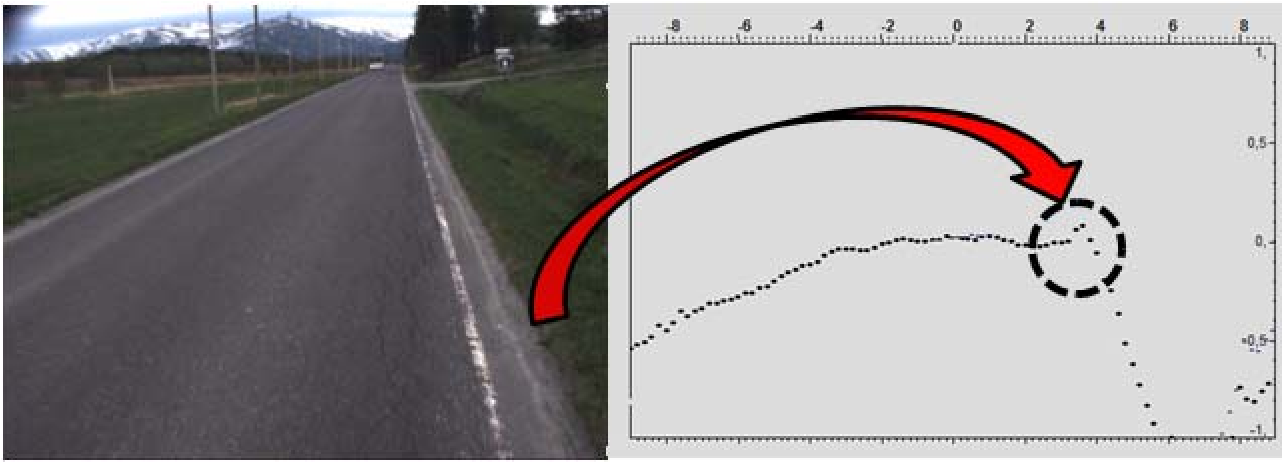

Figure 44: Laser cross section data shows the verge, chainage 24930m. Road cross section shows deformations and the road is dipping to the left.

5.2.2. Road Fv17 Section 30

The starting point of section 30 on road Fv17 was in village of Leland and the end was the ferry dock in Levang. The length of the section was 15486m. In general the drainage was in good condition on this section. The percentage of embankment road profile was much higher (37%) on this section than the average. Figure 45 shows some of the identified drainage deficiencies; clogged culverts and high verges.

Figure 45: Left: Clogged culvert at chainage 4040m, Right: High verge at 11700m.

Erosion can cause significant damages. Figure 46 shows a section where water has washed out a remarkable amount of loose material from the edge of the road. This washout phenomenon can also be seen in the cross section from the laser scanner data (Right).

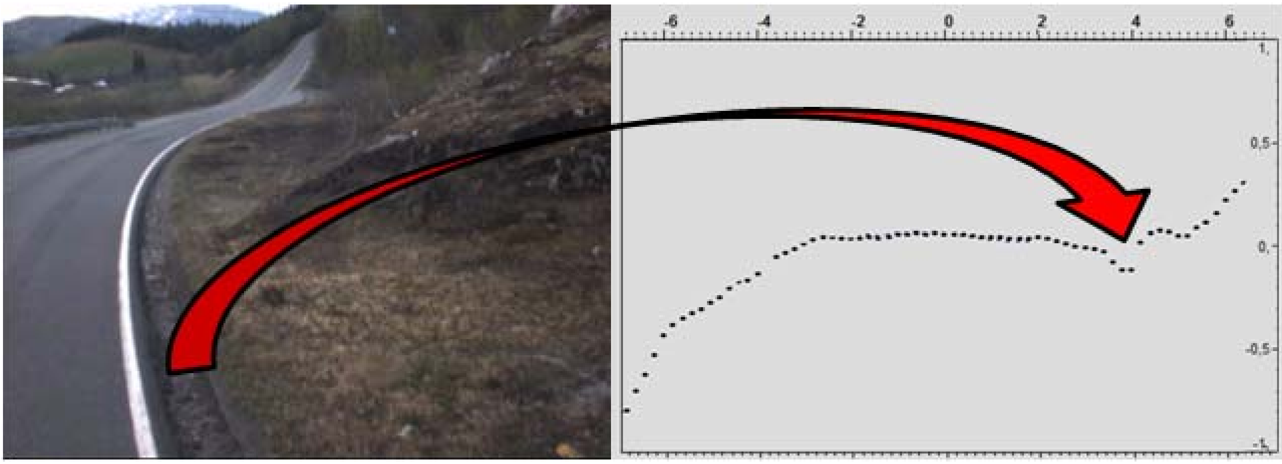

Figure 46: Unstable soil has filled the ditch and erosion can be seen on the still image at the edge of the pavement, and on the laser scanner cross section image (8900m).

5.2.3. Road Fv17 Section 34

The survey on section 34 of road Fv17 started at chainage 100m and ended at chainage 31000m, about 120m after the intersection of the road E12. The length of the section was 30,900m. The field work was divided in two separate parts at the municipality border because of the total length of the section.

At the beginning of the section the elevation changes were small and the road profile was side sloping. The drainage deficiencies were quite typical for this type of road and several sections on the upper side of the slope needed improvement (Figure 47).

Figure 47: Typical drainage shortages for side sloping road profile, (chainage left: 1640m, right: 2900m)

From chainage 7100m to 7250m there was a short section in side sloping road profile where the ditch on the upper side was shallow. Here there were visible damages in the pavement and the road profilometer data indicated higher rutting and roughness values. This section stands out from the surrounding data on the laser scanner pavement rainbow colour map (Figure 48).

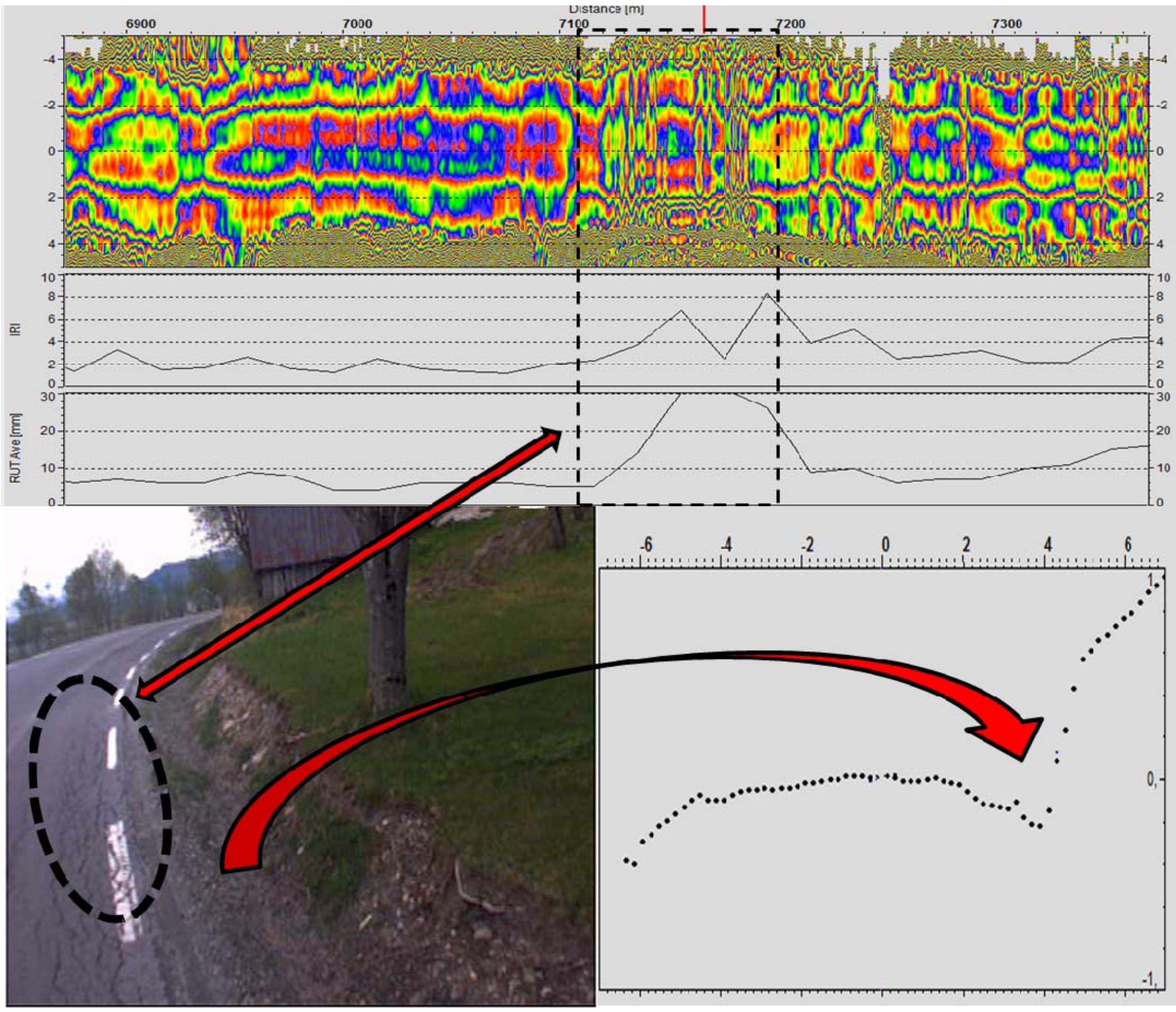

Figure 48: Shallow ditch at chainage 7150m with high IRI and Rutting values, also the surface rainbow colour map (on top) shows deformations in the shape of the pavement surface. The laser scanner cross section image also shows that the gradient slopes towards the left whereas it should be sloped to the right side.

From around chainage 12000m to 27000m the road at first rose to about 300 metres on the mountainside and later came down again. Within this length there were some drainage deficiencies mostly in side sloping road profile. Because of the large elevation changes the risk of erosion needs to be taken into account if drainage improvement actions are to be carried out (Figure 49).

Figure 49: Drainage deficiencies (left: 13950m, right: 16740m).

From chainage 19000m to 21500m, where the road was at its highest elevation, some snow still remained at the time of the field survey. In some sections snow partly covered the ditch bottom which made it difficult to evaluate the drainage condition (Figure 50).

Figure 50: Snow in the ditches, left: chainage 20320m, right: 20710m.

In the last part of the surveyed chainage there were several sections with shallow ditches. Examples of these are shown in Figure 51.

Figure 51: Shallow ditches, chainage left: 27870m, right: 28300m

5.3. ROAD FV78 SECTION 1

Section 1 on road Fv78 started from road E6 at Dalenget and ended just before the bridge over the River Drevjo. The length of the section was 11886m. Nearly all of the chainage lay in side sloping road profile (78%) and there were also three tunnels within the section.

In the first 3 kilometres before the first tunnel there were several severe drainage deficiencies in the upper side of the side sloping profile (Figures 52-53). Further on there were also several lengths where unstable material had filled the ditch and in some cases there was not enough room for an efficient drainage system (Figures 54-55). In the last few kilometres drainage defects became more severe again and verges blocked water flow from the pavement at times.

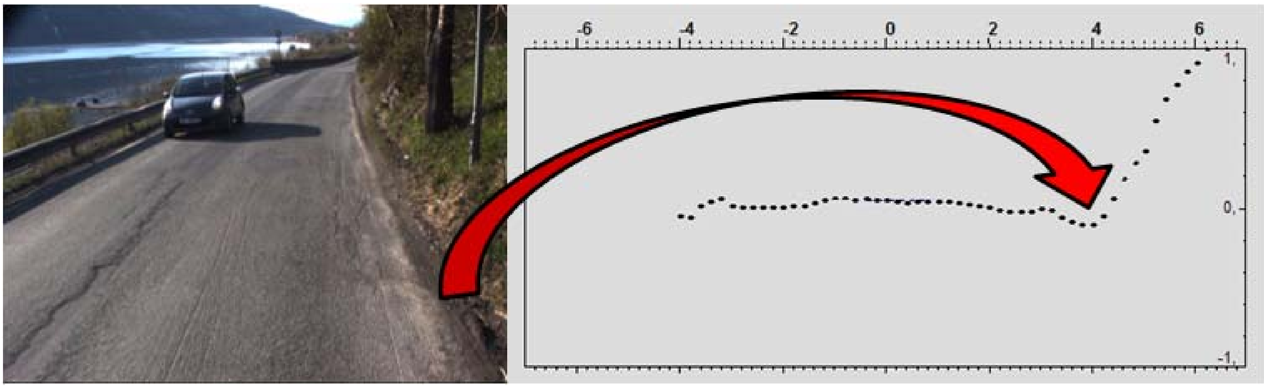

Figure 52: No room for a ditch, also trees and bushes close to the road (chainage 720m).

Figure 53: Drainage problems in steep side sloping road profile before the first tunnel, chainages shown from top left to bottom right: 850m, 1250m, 1330m and 1890m.

Figure 54: No room for a decent ditch, chainage left: 2690m, right: 11500m.

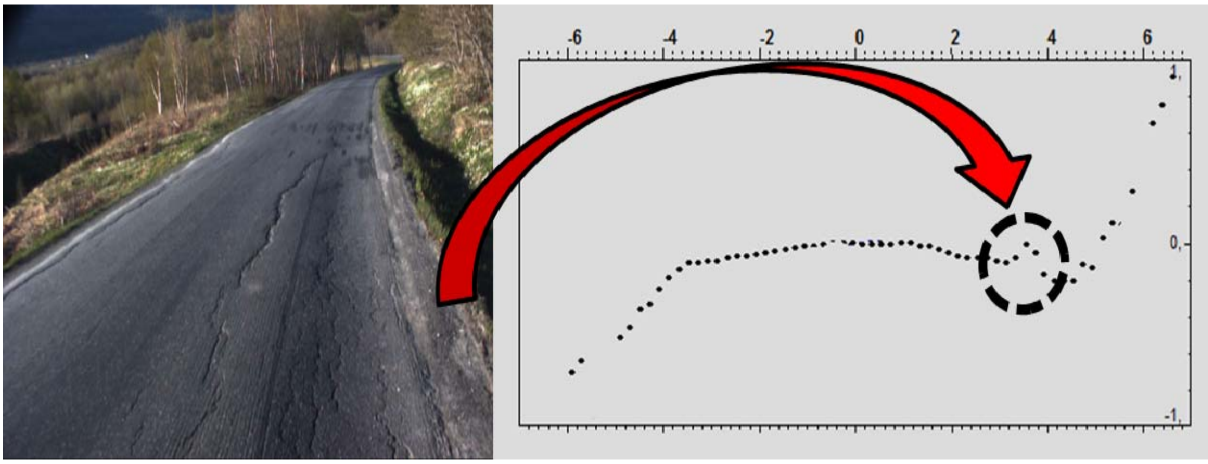

Figure 55: Unstable material has partly filled the ditch and a high verge is blocking water flow (chainage 9840m). Laser scanner data shows also deformation on the right lane.

5.4. ROAD RV 73

5.4.1. Road Rv 73 Section 3

Section 3 on road Rv 73 was from Trofors to the intersection of the road Fv 273, a length of 11375m. The road in this section followed a river valley and the road profile was mainly side sloping (90%). There were several sections with drainage problems typical for this kind of road profile (Figures 56-59).

Figure 56: Inadequate ditch on the upper side of the slope, chainage left: 2380m, right: 3180m.

*Figure 57: Unstable soil has filled the ditch and is blocking the water,
chainage left: 3760m right: 5410m.*

*Figure 58: Steep side slope, not enough room for open ditch,
chainage left: 6165m right: 6190m.*

Figure 59: Erosion damages on the edge of the pavement, chainage left: 7650m, right: 8700m.

5.4.2. Road Rv 73 Section 4

The survey of section 4 of road Rv 73 started from its junction with road Fv 273. At the beginning of the section the road was located in side sloping terrain and the drainage conditions, and drainage defects, were the same as they were in the section 3. Snow started to increasingly hinder the survey from chainage 5000m. The survey continued on the road to around 11000m but later in the office it was decided to stop the analysis at 5500m because of the reduced visibility to the ditches.

The drainage problems along this section related mainly to the side sloping road profile (Figures 60) and too shallow ditches with vegetation slowing down the water flow (Figures 61 and 62).

Figure 60: Problems in the upper side of the side sloping road profile, chainage left: 810m, right: 3480m.

Figure 61: Shallow ditches and verge (also erosion damage on the left photo) were hindering the water flow, chainage left: 3700m, right: 4170m.

Figure 62: Inadequate drainage, chainage 4870m and 5060m.

5.5. ROAD FV 213 (GRAVEL ROAD)

Road Fv 213 commenced from road Fv 212 and ended at chainage 3600m at the end of the road. Most of the road was side sloping (77%), and overall there was need for improvement in the drainage condition. The ditch on the upper side was generally inadequate and needed cleaned.

The laser scanner data from chainage 720m shows the depth of the ditches. The blue line represents the right ditch and the red line represents the left ditch (Figure 63). The depth of the ditches was calculated from the elevation difference between the road centreline and the ditch bottom. The depth of the left ditch at this section was clearly not deep enough when considered against the recommended ditch depth of 20cm-30cm below the structure bottom. The same conditions could be seen at chainage 960m (Figure 64) where the ditches on both sides of the road were shallow. A laser scanner ditch depth analysis was done for the whole section and the result is presented in chapter 6.3.

Figure 63: On the upper side of the slope the ditch was inadequate which is seen both on ditch depth data (top field) and on cross section data (lower arrow). Chainage 722m.

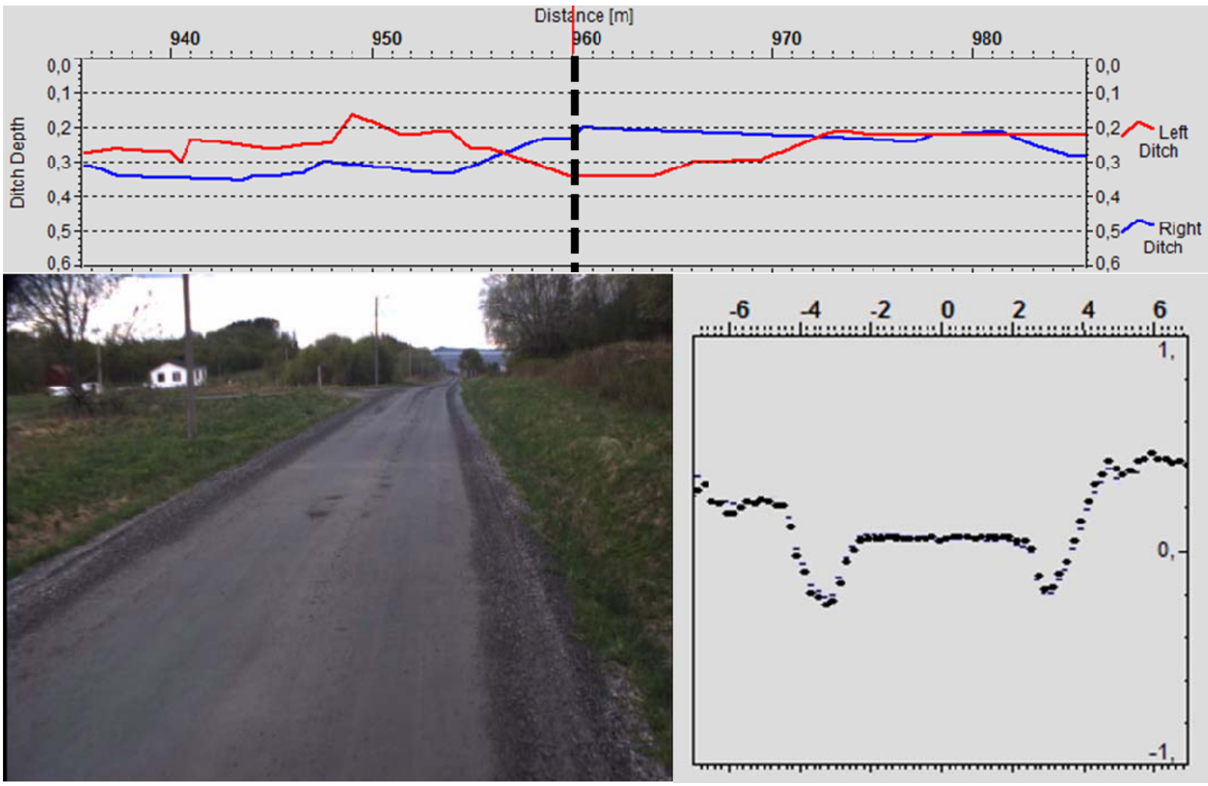

Figure 64: Shallow ditches on both side of the road, chainage 960m.

The ditch on the upper (left) side at chainage 3060m was inadequate as can be seen in photograph and cross-section in Figure 65 (upper arrow). On the right side, which was the lower side of the slope, a ditch was not needed and the drainage was Class 1 (lower arrow).

Figure 65: Inadequate ditch on the upper side of the slope, chainage 3060m.

5.6. ROAD FV 254 (GRAVEL ROAD)

Road Fv 254 was surveyed from road E6 to the end of the road. The length of the section was 8425m. For the first 4 kilometres the road ran alongside a lake where the road profile was side sloping. When the road left the lake the profile remained side sloping at first, but became more variable in the final part.

At the beginning of the road there was a section where the road profile was “even ground” and the drainage was not working efficiently due to the ditch being too shallow and vegetation blocking the water flow (Figures 66).

Figure 66: Shallow ditches at chainage 150m and 1000m.

From 1100m onwards the road profile was side sloping ground for the most part and the drainage problems were typically on the upper side of the slope (Figures 67-69).

Figure 67: Drainage deficiencies on the upper side of the slope (Chainage 1330m and 1440m). Poor drainage is also causing Mode 2 deformations on the road, which can be seen as cracks in the road centre.

Figure 68: Drainage deficiencies on the upper side of the slope (Chainage 2130m and 4840m)

Figure 69: Drainage deficiencies on the upper side of the slope (Chainage 5430mm and 7600m)

A ditch depth calculation was also done for this gravel road section and the result is shown in Chapter 6.3.

6. STATISTICAL DRAINAGE ANALYSIS RESULT

6.1. SUMMARY OF THE ROADS

Many of the surveyed sections were located in the coastal area and some on river valleys. This resulted in the percentage of the side sloping road profile being as high as 71% (Figure 70). The average drainage class was the best in the road sections classified as embankment. This has also been the case overall in the other ROADEX drainage demonstration projects. It was noteworthy that the average drainage class was the worst on sections classified as side sloping ground (Figure 71). In other drainage demonstration projects the poorest drainage conditions have been found in road cuttings, although their percentage of the chainage surveyed has usually been low.

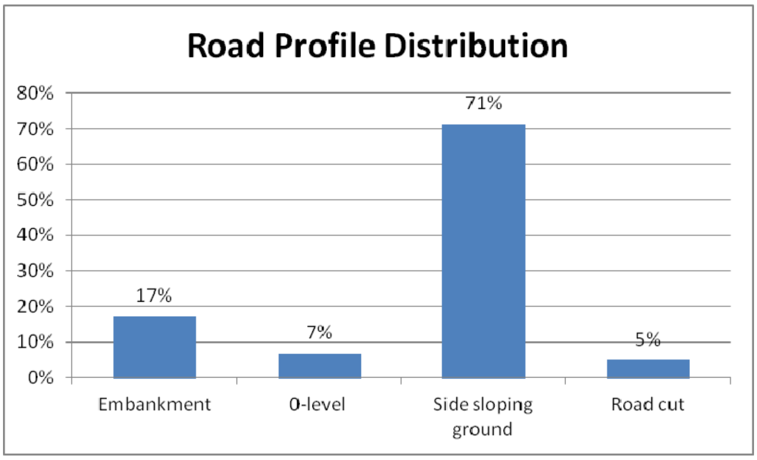

Figure 70: Distribution of the road profiles in the Norwegian demonstration project.

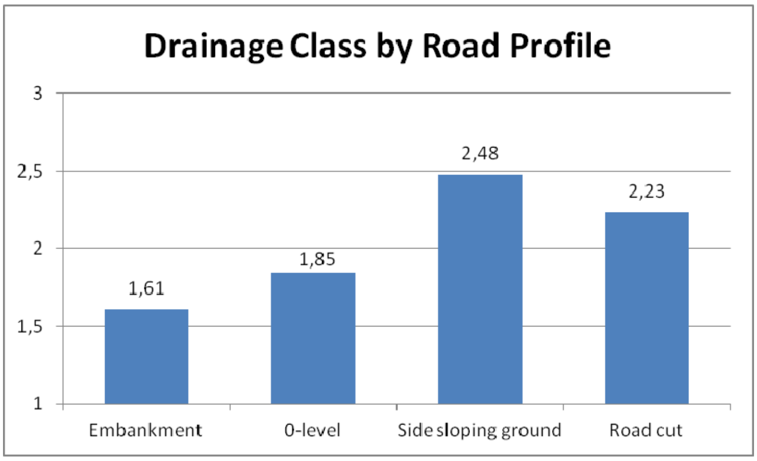

Figure 71: Average drainage class by road profile in the Norwegian demonstration project.

6.1.1. Summary of Drainage and Verge Classes

As already mentioned the drainage condition on the surveyed roads was divided into three different classes: Class 1 (Good condition), Class 2 (Adequate condition) and Class 3 (Poor condition). In the Norwegian demonstration project the greatest part of the ditches were classified drainage Class 1. Verges were classified into two classes: Class 1 (No verges), Class 2 (Verges exist). The majority of the surveyed sections had a drainage class of Class 1 (67%), while 67% of the surveyed chainage did not have verges. The distributions of the drainage classes and verge classes are shown in Figures 72 and 73.

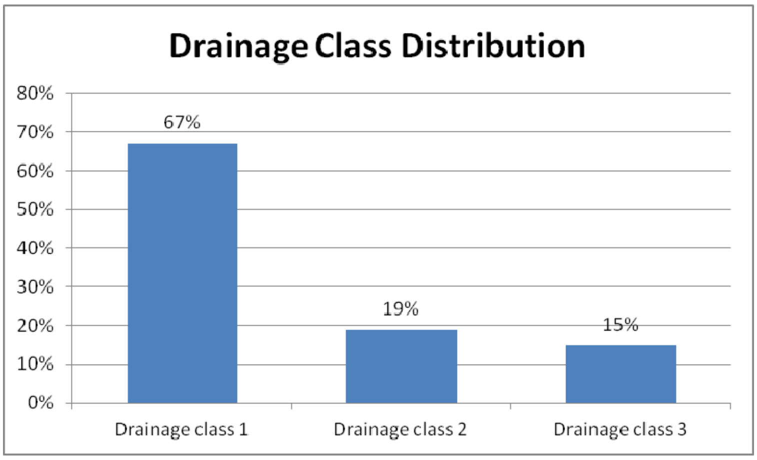

Figure 72: Distribution of drainage class in the Norwegian demonstration project.

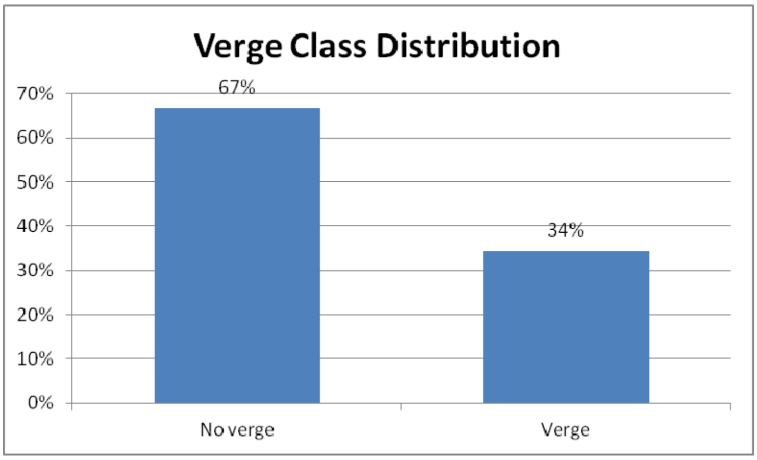

Figure 73: Distribution of verge class in the Norwegian demonstration project.

6.1.2. Drainage Condition and the Presence of the Verges in Surveyed Sections

The drainage classification of each road section surveyed was examined statistically. The worst sections for drainage classification in average were the E6 section 12 and the Rv73 section 3. However both of the roads Fv17 and E6 had several sections which were in quite good drainage condition. The distribution of average drainage classes in each surveyed section is shown in Figure 74.

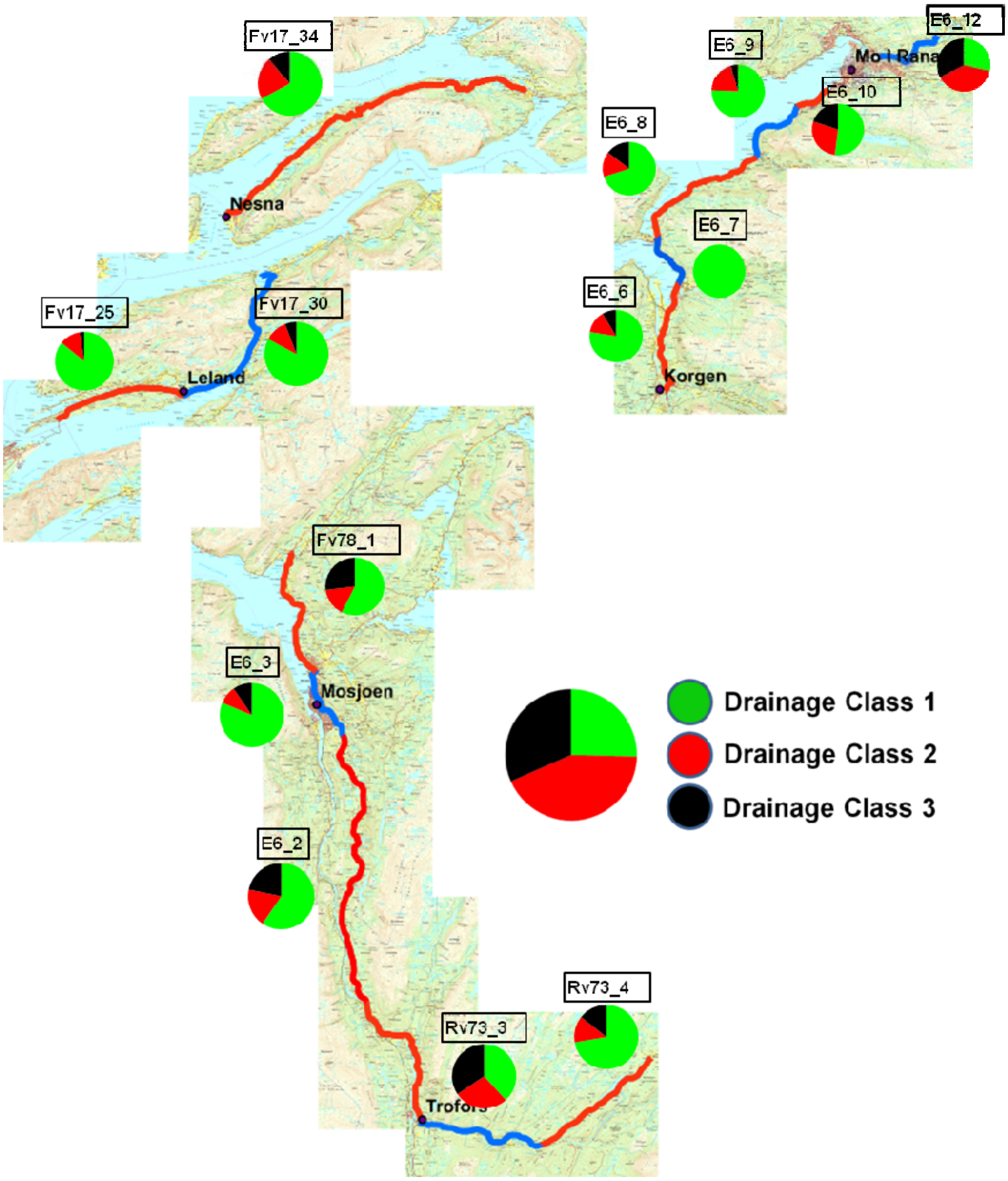

Figure 74: Distribution of average drainage classes in the surveyed paved roads.

As already mentioned verges were only classified into two classes. The major part of the surveyed chainage did not have verges but on about one third of the road length (Figure 75) some kind of verge was found. Most of the chainages where verges existed the verges were low and only had minor effects on drainage. Sections 3, 10 and 12 on the road E6 had the highest percentage of verges, while roads Fv17 and Rv73 had significantly less verges.

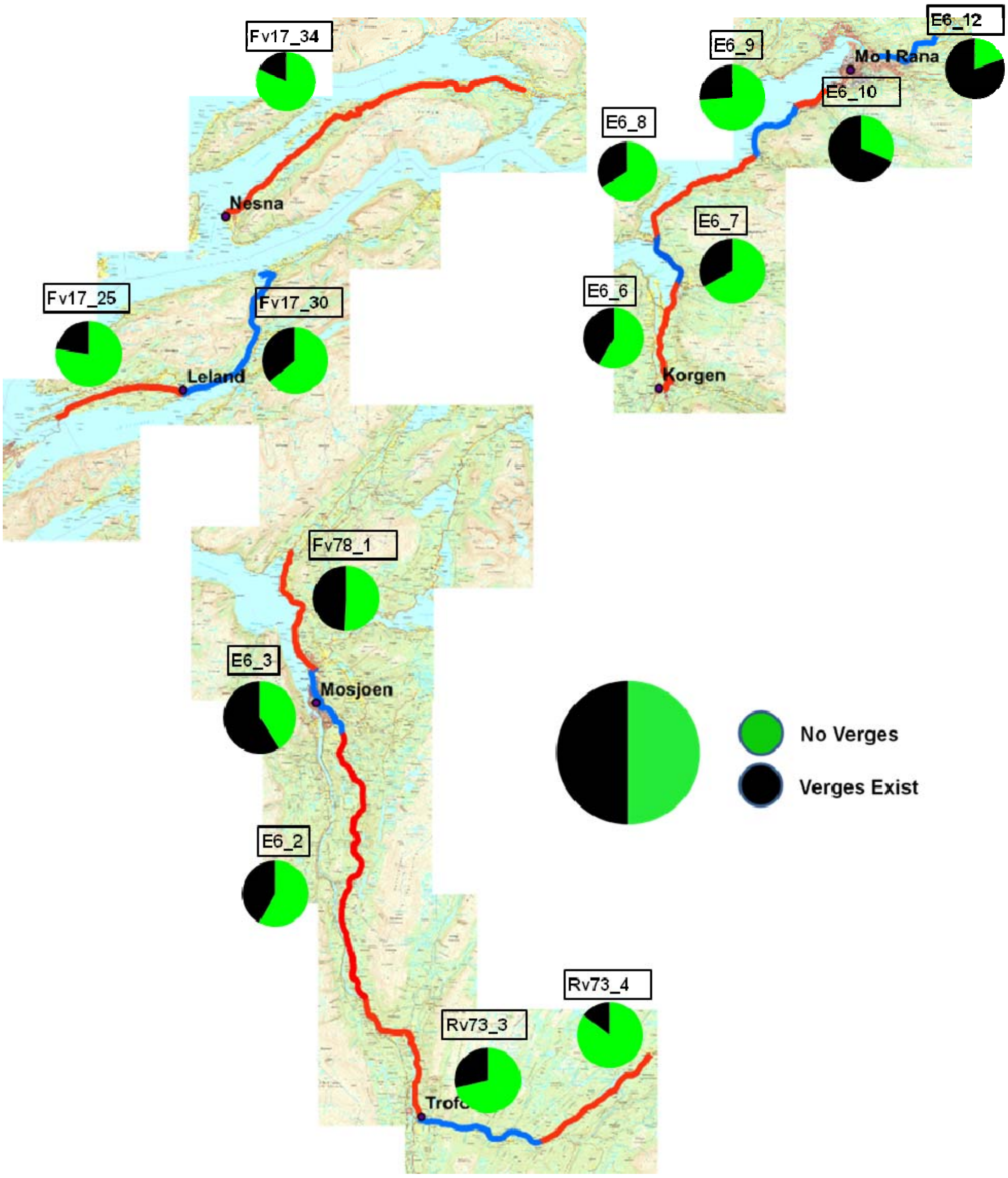

Figure 75: Verge classification on the surveyed paved roads.

6.2. DRAINAGE AND ROAD PERFORMANCE

6.2.1. Effect of Drainage on Roughness and Rutting

Overall the classification of drainage condition on the Norwegian demonstration project correlated quite well with IRI and rutting as was the case with previous drainage projects. The road profilometer data of the roads sections surveyed was averaged to 20 metres. Experiences from other drainage projects have shown that the profilometer data should be as accurate as possible. This might have had some averaging effect also on the statistical drainage results.

A major part (72%) of the surveyed was in side sloping ground. It is usually the case that the most problems on roads on side sloping ground take place in the upper side of the slope, and that the lower side usually has less damage. This is because in side sloping ground any water tries to flow “through” the road using the shortest possible path. If the drainage in the upper side of the side slope is not in good condition the water will stay in the ditch, causing consequential problems to the road which are usually visible and measurable on the same side of the road.

The section on road 78 was omitted from the statistical analysis because the data from the profilometer surveys did not correlate with the current situation on the road. A reason for this could be that the pavement condition and age varied along the section and that substantial pavement patching had been carried out. Figure 76 shows one example where the IRI and rutting values were both low even though the pavement was in quite poor condition and there were visible damages and also rutting. The drainage system on the right was inadequate and was classified as drainage Class 3.

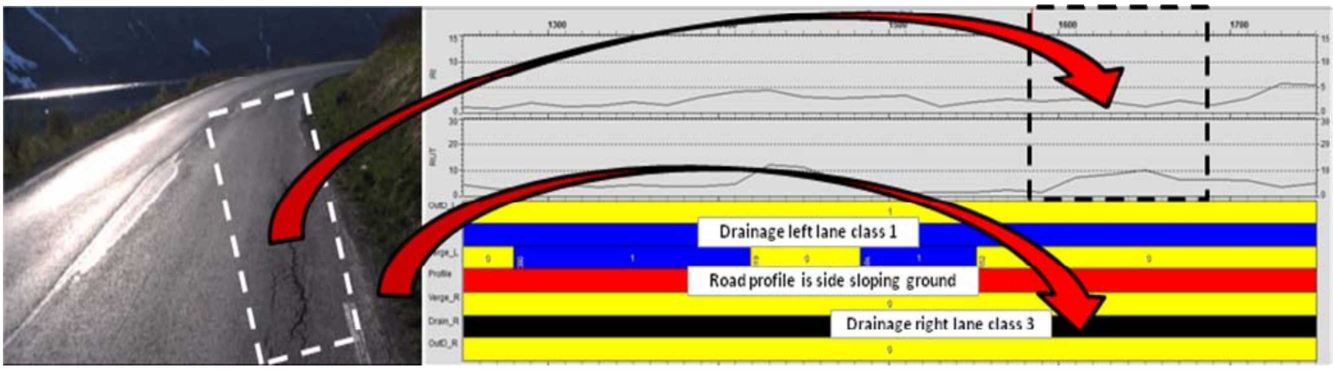

Figure 76: Drainage problems and severe damages on the pavement on the right lane. Profilometer data (upper arrow) shows low values which do not reflect the actual condition of the road. (chainage 1580-1680m).

It was decided that the statistical summary charts for the surveyed sections should be presented as ratios. The reason for this was that the difference in the basic level of roughness and rutting on the different roads was high, as can be seen on Figures 77 and 78. This variation resulted in somewhat skewed results for IRI and Rutting calculations, both by drainage and verge, if calculated only by raw profilometer data.

The deepest rutting values classified according to drainage class were on road E6, and the lowest were on road Rv73. On each road the rutting depth increased when the drainage condition was poorer (Figure 77).

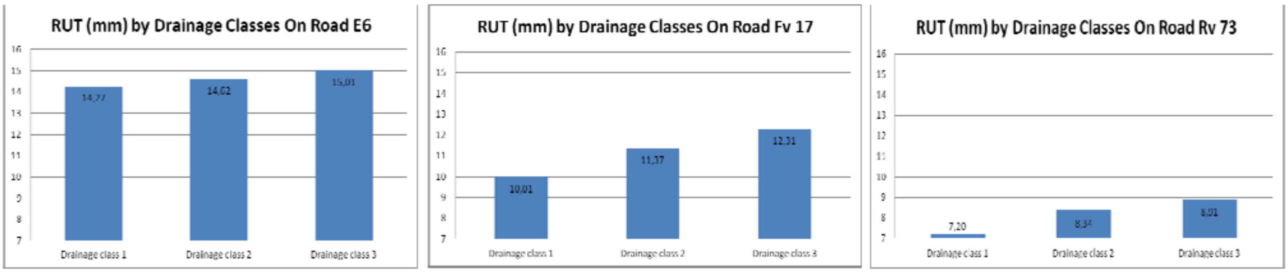

Figure 77: Mean average rut depth values classified by drainage classes on the surveyed roads.

Table 2 shows the weighed ratio of the average rutting in each drainage class.

Table 2: Weighted average rutting ratio by drainage class.

Drainage Class 1	1,00
Drainage Class 2	1,08
Drainage Class 3	1,14

Figure 78 presents the mean average IRI values by each drainage class. The highest roughness values were on road Rv 73 and the lowest values were on road E6. The IRI values followed the same pattern as the rutting values and increased when the drainage was classified poorest (i.e. drainage Classes 2 & 3). The average roughness ratios are summarised in Table 3.

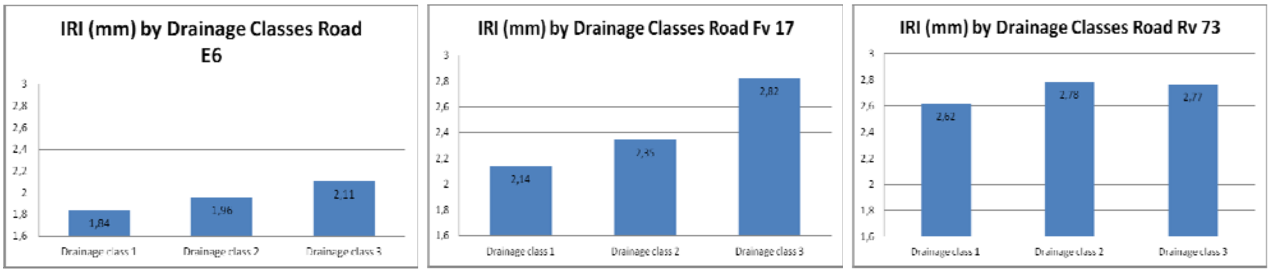

Figure 78: The mean average IRI values classified by drainage classes in surveyed roads.

Table 3: Weighted average roughness ratio by drainage class.

Drainage Class 1	1,00
Drainage Class 2	1,08
Drainage Class 3	1,20

6.2.2. Effect of Verges on Roughness and Rutting

Verges also have an effect on the roughness and rutting of a road. The mean rutting values for each road are presented in Figure 79. Overall, it appears that the presence of roadside verges has even a bigger affect on rutting values compared to drainage problems.

The deepest ruts, classified according to verge class, were on road E6 and the lowest on road Rv73 (Figure 79). The trend follows the same circumstances as drainage class.

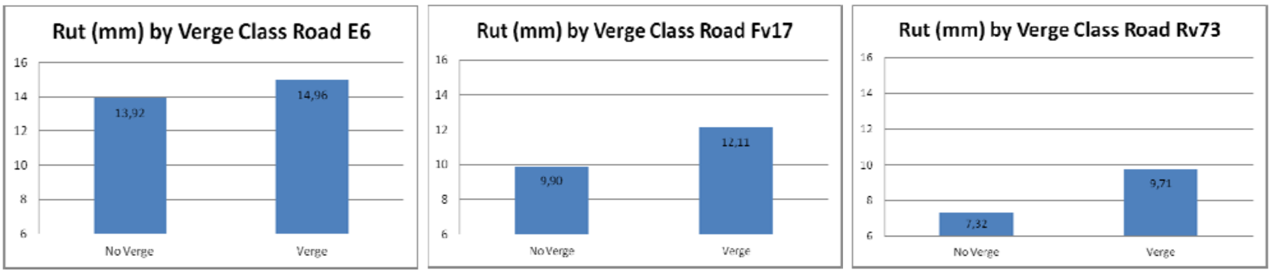

Figure 79: Mean rutting values classified by verge classes in surveyed roads.

Where verges existed, the weighted average rutting ratio was 1.16 times higher compared to thise lengths where verges did not exist (Table 4).

Table 4: Weighted average rutting ratio by verge classification.

No Verge	1,00
Verge Exist	1,16

In contrast to rut depths the highest roughness values classified by verge were on road Rv 73 and the lowest values on road E6 (Figure 80).

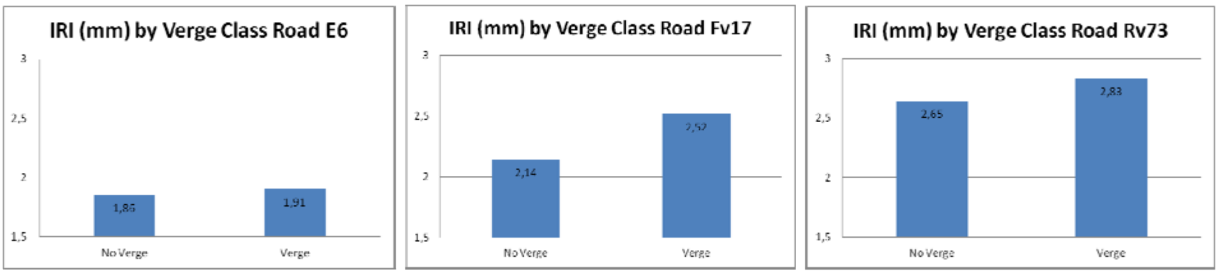

Figure 80: Mean roughness values classified by verge classes in surveyed roads.

Table 5 presents the weighted average IRI ratio by each verge class. The weighted average IRI ratio between situation “no verge” and “verge exists” is 1.08.

Table 5: Weighted average rouhgness ratio by verge classification.

No Verge	1,00
Verge Exist	1,08

6.3. LASER SCANNER RESULTS

The laser scanner ditch depth calculation method was tested on two paved road sections, and on both surveyed gravel roads. The paved sections tested were section 3 on road Rv 73 and section 12 on road E6. Nearly all of the chainage on both paved road sections was in side sloping ground. Only the upper side ditch depth was considered during the calculation as the drainage condition on that side was seen to be most important. Most of the chainage on the lower sides of the sections did not have a ditch at all and was mostly on embankment.

A GPR survey was not carried out in the Norwegian demonstration project and thus the actual structure thicknesses were not available. For the paved road sections, typical road structure thicknesses of 50cm and 80cm were used as reference thicknesses for the ditch depth. In the ditch depth view in Figure 81 the darker grey represents the 50cm structure layer and the lighter grey represents the 80cm structure bottom. These are given as a reference guide for the calculated left ditch depth which is shown upmost in the top panel as a red line.

According to the Nordic countries recommendations ditch depths should be 20-30cm lower than the bottom of the road structure. Figure 81 shows an example from road E6 section 12, chainage 900m - 1200m. This shows a shallow ditch in the ditch depth analysis field (top panel) and the ditch depth map (right). Chainage 1080m is marked with the black arrow both in the map and in the ditch depth analysis field. The same chainage is also shown in the still photograph from the survey video.

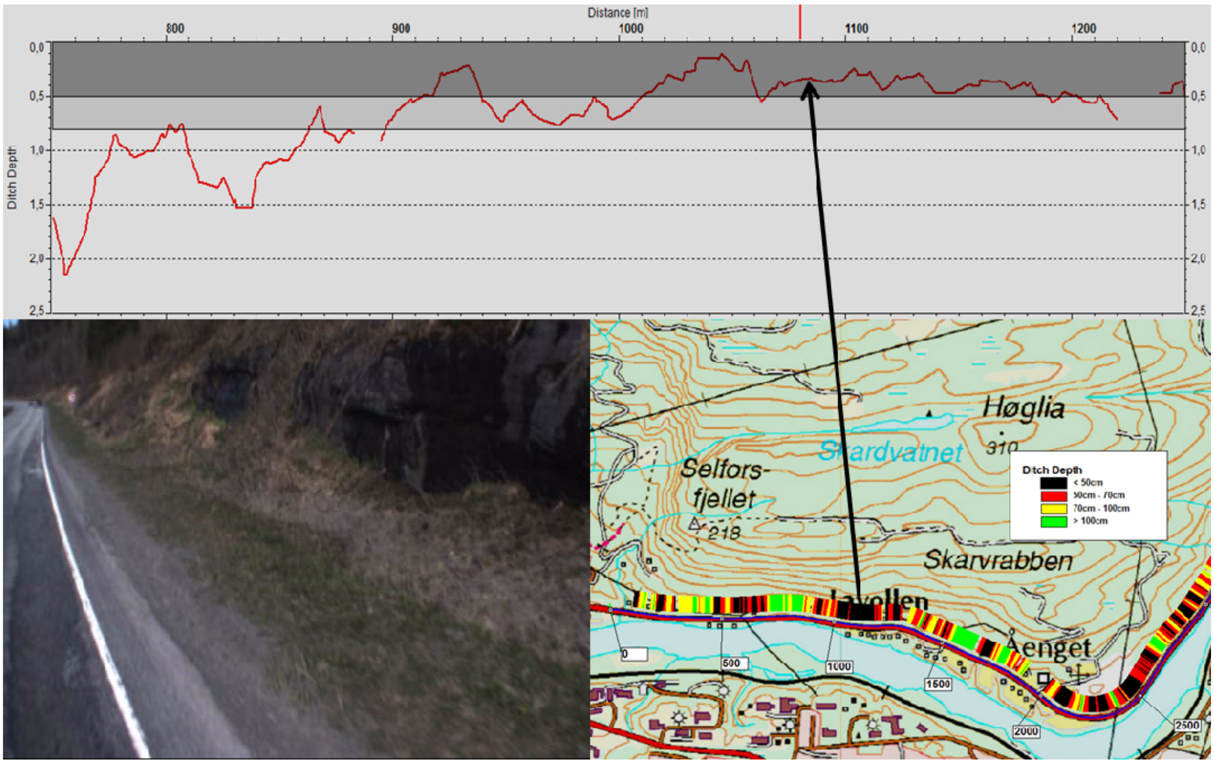

Figure 81: Ditch depth in the analysis field and in the map view, road E6 section 12, chainage 900m - 1200m.

A GIS map of the ditch depth for the whole of section 12 of road E6 is given in Figure 82.

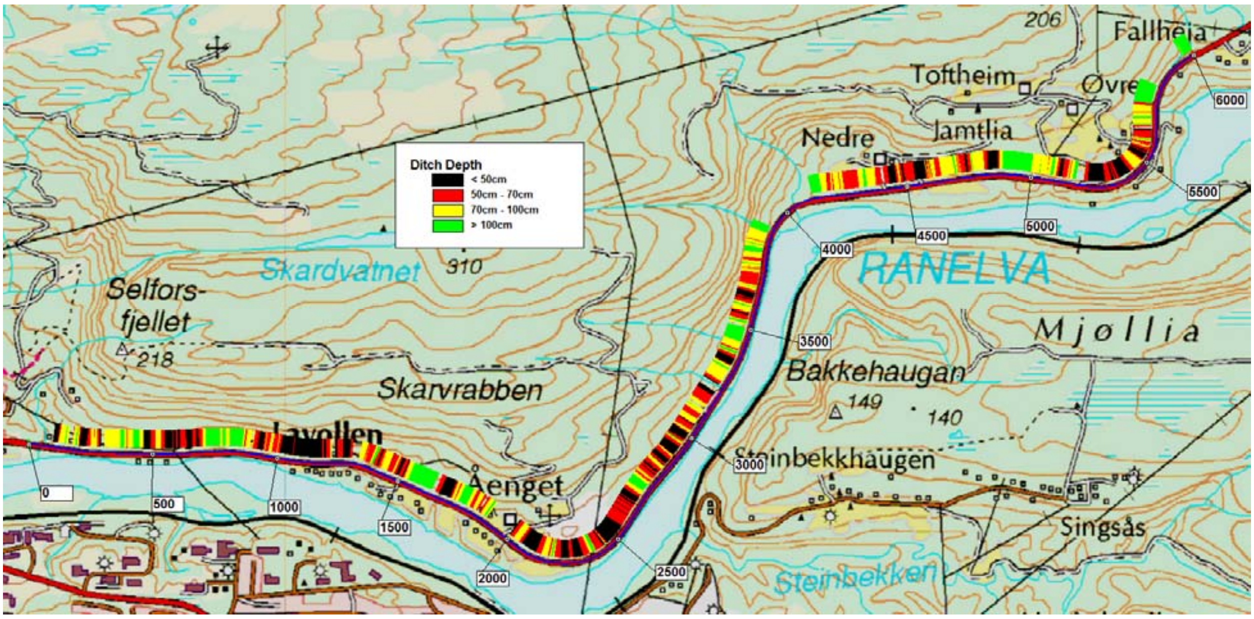

Figure 82: GIS ditch depth map of section 12 on road E6.

Section 3 of road Rv 73 had problems with the depth of the ditch on the upper side of the side slope, and especially in the chainage from 7000m to 8500m. (Figure 83). The GIS map of the section in Figure 83shows the ditch depth along the section, and in the analysis field there is a detailed view from 7400m to 7900m. The black arrow indicates chainage 7650m in both views.

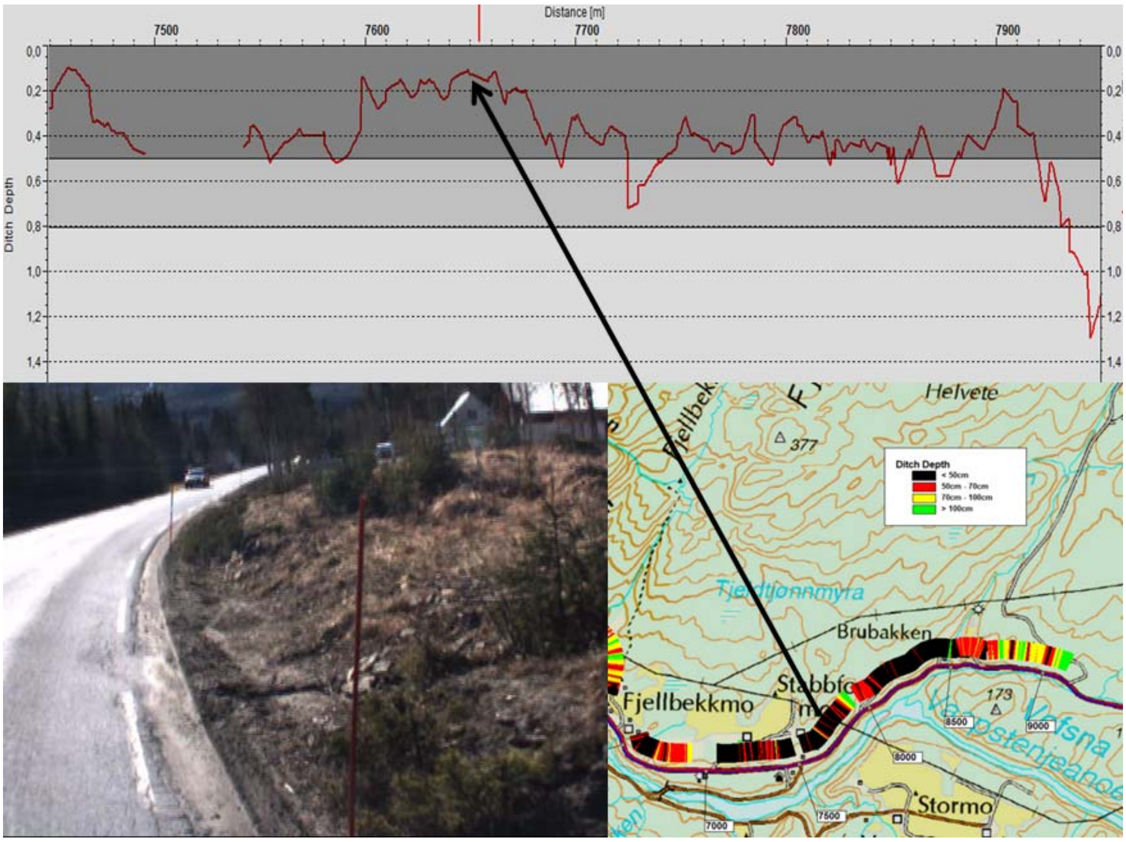

Figure 83: Ditch depth in the map view and analysis field,
Section 3, road Rv 73, chainage 7000m – 8500m.

As already mentioned the two surveyed gravel roads were also tested for the ditch depth calculation. According to the Nordic countries recommendations the target ditch depth for gravel roads is also 20cm-30cm below the road structures. This meant that a ditch depth at least 80cm was deep enough and a ditch shallower than 50cm was not sufficient. The measured road structure thickness was not available for the gravel roads however, and an assumption was made that the road structure would be about 50cm thick. The calculated ditch depth was classified into 4 classes for the purposes of reporting: <50cm, 50-70cm, 70-100cm and >100cm.

Figures 84 and 85 show the result of the ditch depth calculation for roads Fv213 and Fv254 as GIS maps.

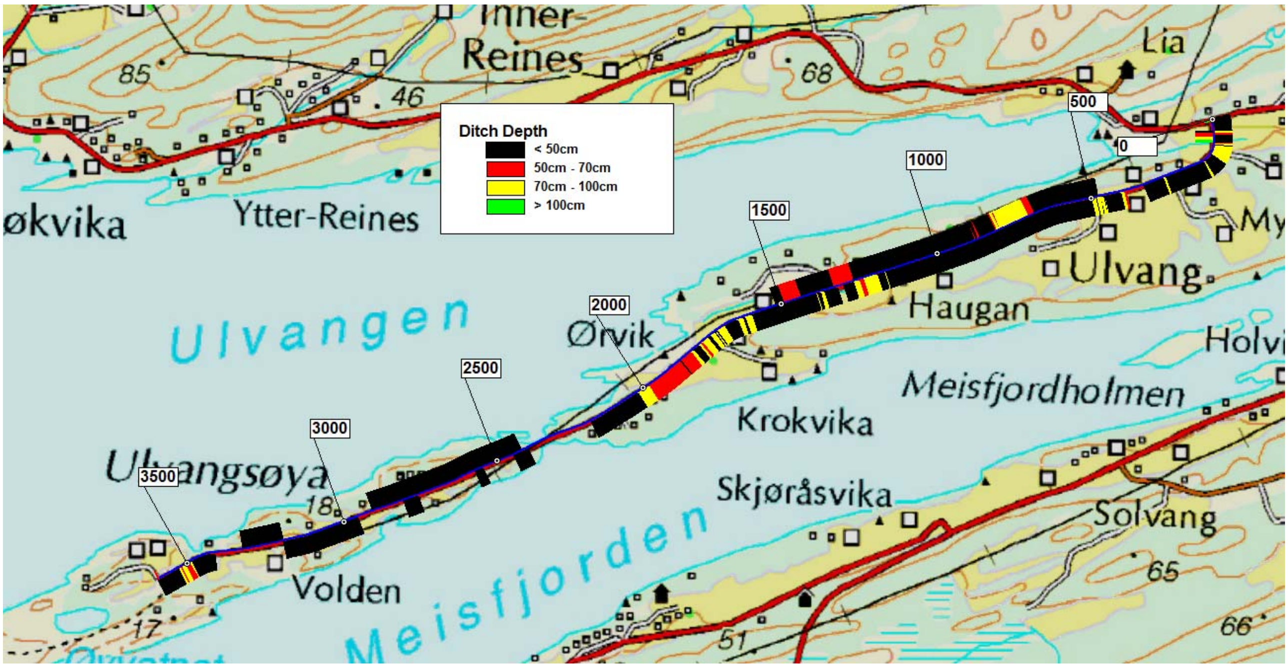

Figure 84: GIS ditch depth map of road Fv 213.

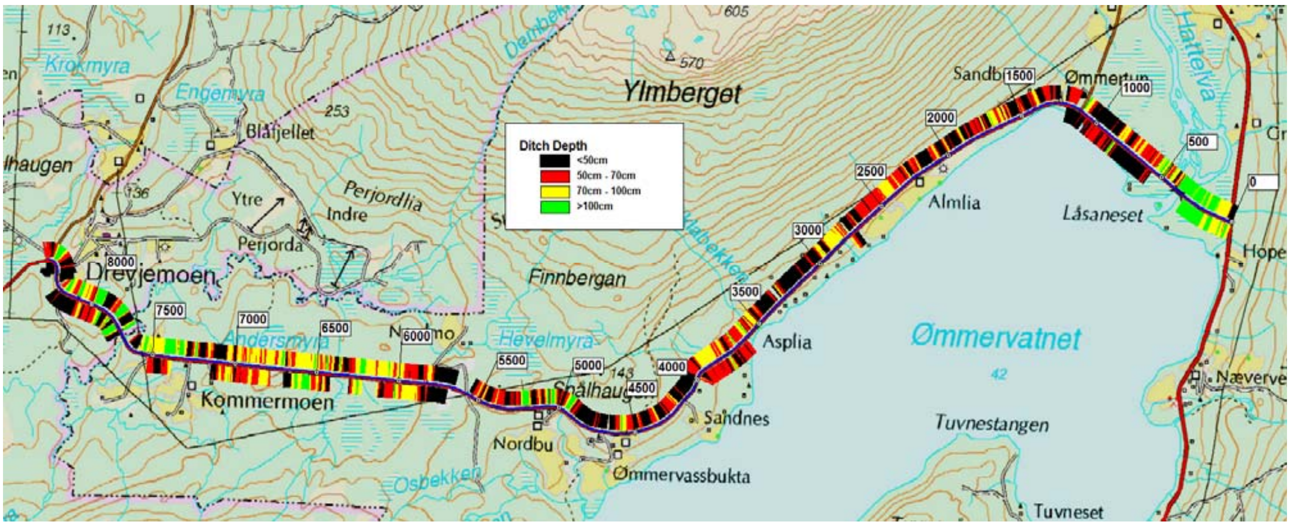

Figure 85: GIS ditch depth map of road Fv 254.

7. DRAINAGE AND PAVEMENT LIFE TIME

The lifetime of a road section is determined by its worst 10 % sub-sections. Based on pavement life time analysis, improving the drainage condition in critical sections and maintaining it in good condition will increase the pavement lifetimes in most of the surveyed road sections by at least 1.2 - 1.5 times. The conclusion is that if rehabilitation and drainage maintenance can be carried out together in an economic fashion they can lead to major savings in annual paved road network costs.

In order to calculate how much a well-functioning drainage system can affect the life cycle costs of a pavement it is important to know the costs of improving the drainage. Normally the costs of drainage maintenance are much smaller than repaving. In some surveyed sections it is likely that the drainage solutions will be challenging and in some places expensive, due to the local constraints involved, but the pay-back time is expected to be short. If the drainage can be improved, the potential savings in annual paving costs could be up to 30% according to calculations made in earlier ROADEX projects.

Figure 86 shows the results of pavement lifetime factor calculations (the ratio of the worst 10% rutting class) for the roads surveyed in the Region Nord. These factors varied from a value <1.05 for some sections of the road E6, to a value >1.5 for the section 25 on Fv17 road. Overall the Fv17 and Rv73 on average appear to have worse lifetime factors, even when the drainage is on average (especially on Fv17) better than road E6. Road Fv78 was left out of the analysis because of the quality of the old profilometer data. As mentioned earlier, the averaging of the profilometer data to 20 metres could skew the results of the pavement life time calculations.

Drainage improvement will be the most economical on those sections which have a lifetime factor greater than 1.5. For example on surveyed sections in Region Nord in Norway, the improvement would be the most economical on section 25 of the road Fv17.

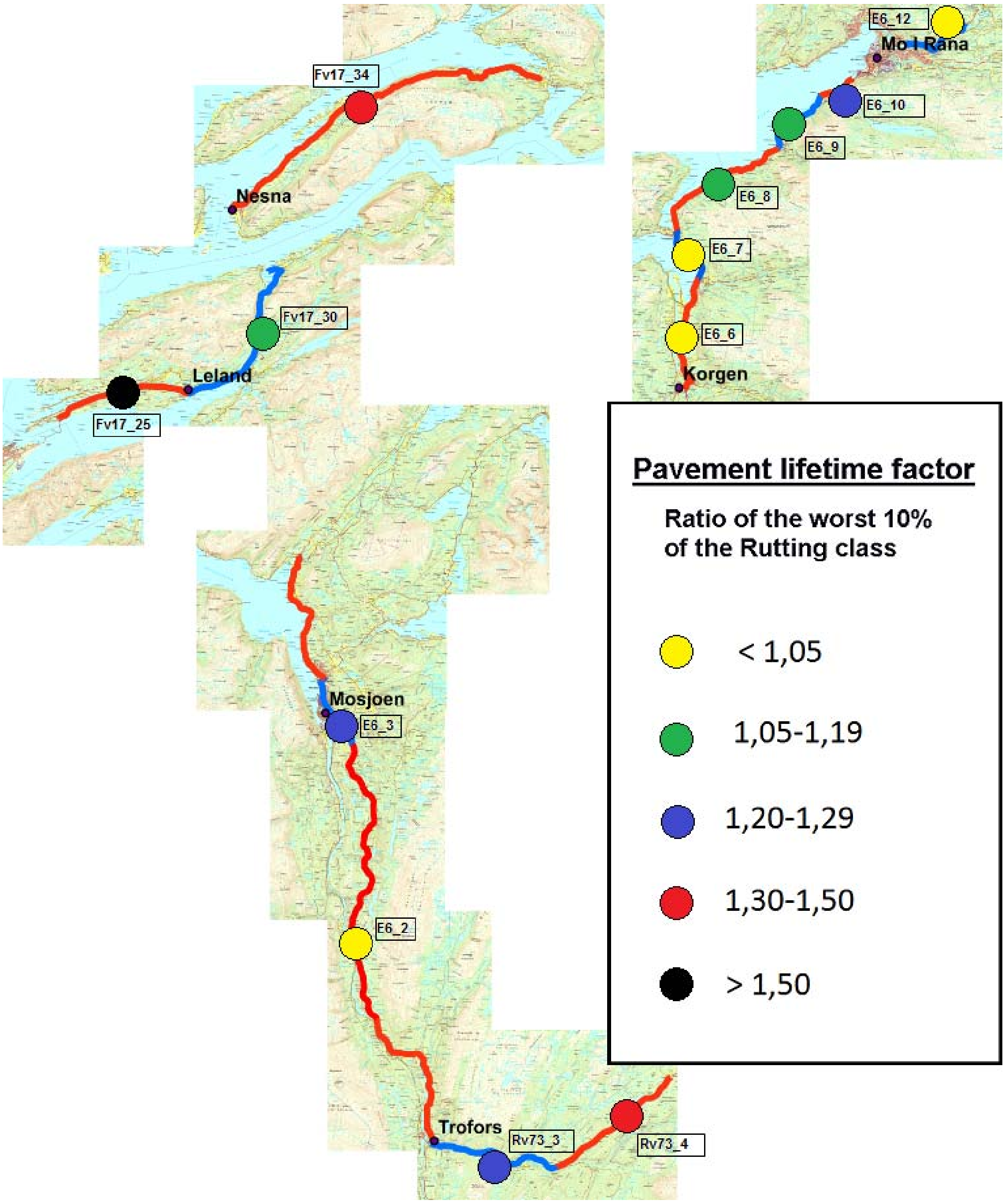

Figure 86: Pavement lifetime factor for the roads surveyed in the Region Nord, Norway.

8. DRAINAGE IMPROVEMENT DESIGN

In many ROADEX countries drainage, and drainage improvement, has a low priority despite research proving that it is important that road drainage should be kept in good condition. At present a number of issues have to be addressed when planning drainage work. What is the best way to organize it? Should the work be the responsibility of the maintenance or pavement contractor, etc?

It is not just enough that problematic sites are improved, it is vital that the improved sections are also kept in a good condition. Constant monitoring and maintenance of the improved drainage is vital therefore to ensure that good drainage work remains effective.

When a drainage improvement is carried out the work should be done carefully. It is more important to pay attention to the longitudinal gradient of the ditch and the removal of obstacles blocking the water flow (big stones, flowing soil, etc.), than to dig the ditch deeper. Ditches that are dug too deep increase the risk of side slope erosion. It is recommended that the bottom of the ditch should be 20-30cm deeper than the bottom of the road structure and that the longitudinal gradient of the side ditch should be at least 4 ‰ (4 mm/m).

If the ditch has steep side slopes, it is better to carry out the improvement works in the early summer so that the local vegetation has enough time to grow back before winter to reduce the risk of erosion.

As part of the drainage demonstration project in the Region Nord proposals were made to improve the drainage in section 12 of road E6. The aim was to give an example of how to identify problematic sections. In the GIS map in Figure 87 the darker blue lines represent the sections which need drainage maintenance in the ditches, and the lighter blue lines represent the sections which have problems with the verge.

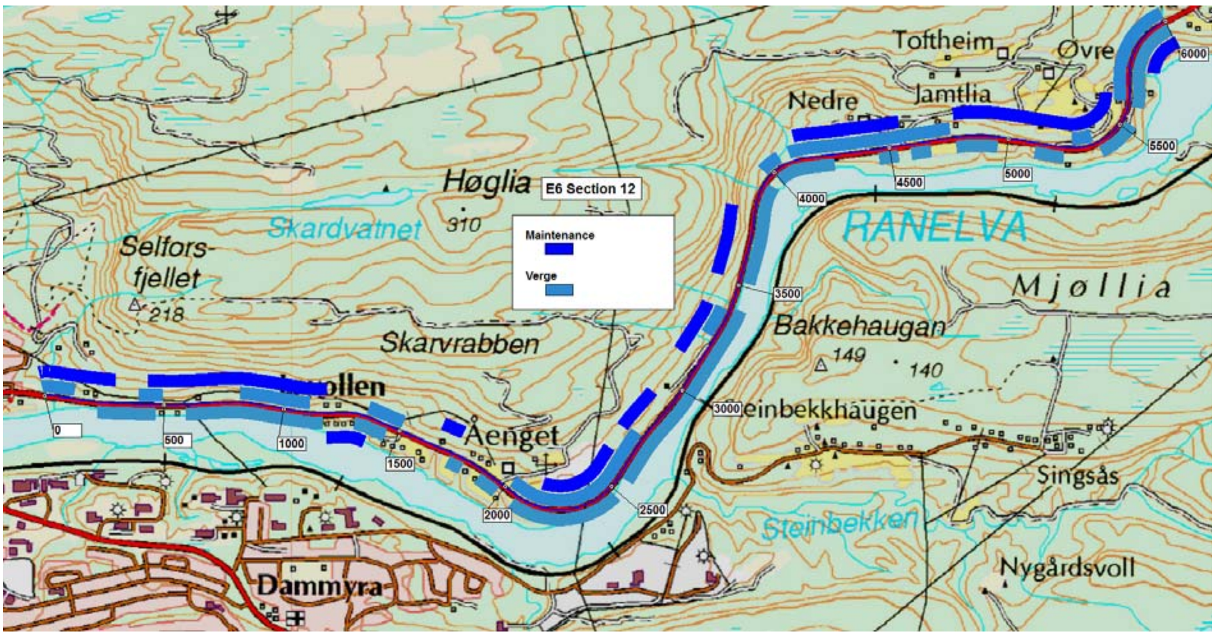

Figure 87: Road E6 section 12 drainage maintenance map.

In nearly all of section 12 the road profile was in side sloping ground (94.6%) and mostly the drainage problems were on upper side of the slope. On the left side of the road approximately 60% of the chainage needed maintenance attention, whereas only 8% needed it on the right side.

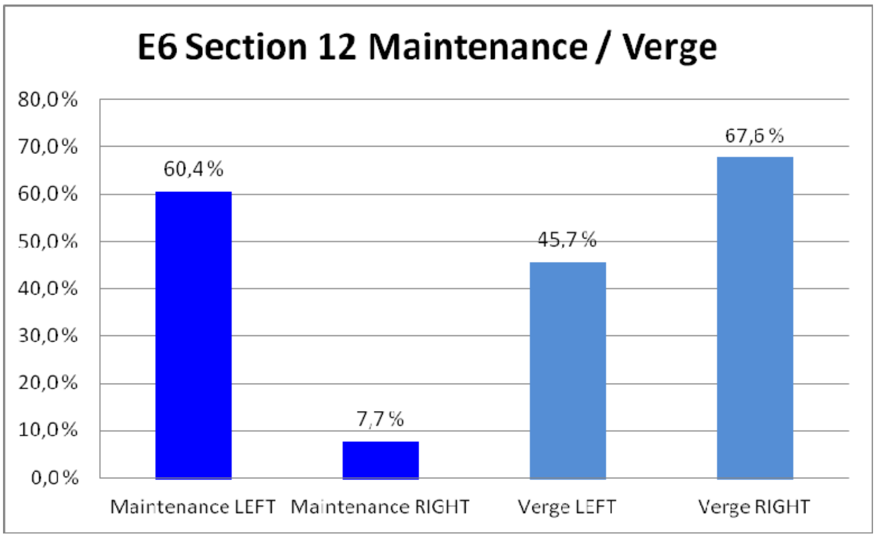

Figure 88: Percentage of maintenance action and the presence of verge on road E6 section 12.

9. CONCLUSIONS

The drainage condition of the demonstration road sections in Region Nord, Norway varied greatly. Good road sections with faultless drainage systems were seen, but there were also road sections with poor drainage. Because of the terrain the dominating road profile was side sloping ground, and in total 71% of the chainage was in that road profile.

As already mentioned the profilometer data of the surveyed roads was averaged to 20 metres which could have skewed the statistical results somewhat. Despite this the results correlated reasonably well with rut depth and roughness ratios. On average the rutting ratios in drainage Class 2 were about 8% higher than in drainage Class 1, and in drainage Class 3 about 14% higher. The IRI ratios were even higher than the rutting ratios in drainage Classes 2 and 3. In drainage Class 2 the IRI ratio was 8% higher higher compared to drainage Class 1, and in drainage Class 3 the IRI ratio was 20% higher.

Several road sections had a calculated pavement life time factor higher than 1.2 and in one section the factor was above 1.5 which indicated that substantial savings could be gained if the drainage was to be improved.

In Nordic countries verges are considered to be harmful features and are removed. In the earlier ROADEX drainage projects in Ireland and in Scotland, where the verges are deliberately constructed and offlets guide the water from the road surface, the correlation between the presence of verges and poor drainage was strong. The calculations in Region Nord project showed that the presence of verges also had an impact on Norwegian roads. In those road sections where verges were found during the survey the rutting ratio was 16% higher than those sections without verges, and the IRI ratio was 8% higher.

In recent years the greatest advancements in all of the NDT techniques used in road surveys have been made with laser scanners. It is inevitable that these systems will become a standard tool for a variety of tasks in road condition management. It is very important however to pay attention to the local conditions during laser scanner surveys. The accuracy of the laser scanner survey can be reduced by a number of factors that affect visibility, such as dust, rain, fog or snow. High vegetation can also prevent the system from obtaining data on the actual ground surface. In the Norwegian surveys there were a couple of sections high on the mountains that had snow in the ditches which prevented the laser scanners from seeing the bottom during the survey.

The laser scanner survey provided useful information in the project in Region Nord about the level of ditches compared to the road surface. The depth of the ditches was calculated in the project from laser scanner data on paved and gravel roads. The results showed that the sections which the laser scanner data identified as deficient correlated with visual drainage classifications. The laser scanner data was also useful in recording the shape of the road cross section.

It is recommended that in future laser scanner surveys should be done together with a GPR survey. This will ensure that the bottom of the road structure can be measured at the same time. A ROADEX demonstration project carried out earlier in Sweden showed that if the ditch was 20-30cm deeper than the bottom of the road structure, the road should function relatively well.

ROADEX PROJECT REPORTS (1998–2012)

This report is one of a suite of reports and case studies on the management of low volume roads produced by the ROADEX project over the period 1998-2012. These reports cover a wide range of topics as below.

- Climate change adaptation
- Cost savings and benefits accruing to ROADEX technologies
- Dealing with bearing capacity problems on low volume roads constructed on peat
- Design and repair of roads suffering from spring thaw weakening
- Drainage guidelines
- Environmental guidelines & checklist
- Forest road policies
- Generation of 'snow smoke' behind heavy vehicles
- Health issues raised by poorly maintained road networks
- Managing drainage on low volume roads
- Managing peat related problems on low volume roads
- Managing permanent deformation in low volume roads
- Managing spring thaw weakening on low volume roads
- Monitoring low volume roads
- New survey techniques in drainage evaluation
- Permanent deformation, from theory to practice
- Risk analyses on low volume roads
- Road condition management of low volume roads
- Road friendly vehicles & tyre pressure control
- Road widening guidelines
- Socio-economic impacts of road conditions on low volume roads
- Structural innovations for low volume roads
- Treatment of moisture susceptible materials
- Tyre pressure control on timber haulage vehicles
- Understanding low volume pavement response to heavy traffic loading
- User perspectives on the road service level in ROADEX areas
- Vehicle and human vibration due to road condition
- Winter maintenance practice in the Northern Periphery

All of these reports, and others, are available for download free of charge from the ROADEX website at www.ROADEX.org.