ROADEX
Implementing Accessibility

Northern Periphery Programme 2007–2013

European Union
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SUMMARY OF DRAINAGE ANALYSIS IN ICELAND

Demonstration Project Report

SAMANTEKT AFVÖTNUNARGREININGAR Á ÍSLANDI

ÁGRIP

Afvötnun er einn af mikilvægustu þáttum sem þarf að hafa í huga við hönnun og viðhald vega. Almennt er talið að vegir virki vel og endist lengur við þurrar aðstæður. Rannsóknir hafa sýnt fram á að léleg afvötnun er oft aðalorsök skemmda á vegi og skapar vandamál varðandi langtíma viðhald vegarins. Samt sem áður hefur þessari þekkingu ekki alltaf verið beitt í raun með þeim afleiðingum að almennt er afvötnun vegakerfa ekki í góðu ásigkomulagi. Fyrri ROADEX verkefni hafa sýnt fram á að léleg afvötnun er eitt stærsta vandamál sem steðjar að fáförnum vegum í dreifbýli norðurjaðarsvæða Evrópu og hluta stofnvegakerfa svæðanna. Endurbætur á og viðhald afvötnunarkerfa hefur því mikil áhrif í átt að minna niðurbroti vega og hafa ROADEX rannsóknir sýnt fram á endurbætur á afvötnun getur aukið líftíma slitlags 1,5 til 2,0 sinnum. Aðgerðir er miða að betri afvötnun eru því mjög ábatasamar og skila sér í meiriháttar sparnaði í árlegum viðhaldskostnaði slitalags.

Í gegnum ROADEX verkefni hefur verið þróuð aðferðarfræði til þess að greina afvötnun og staðsetja þá vegkafla sem þarfnast endurbóta og reglubundins viðhalds á afvötnunarkerfi. Í greiningunni eru gögnum safnað frá öllum þeim þáttum sem hafa áhrif á afvötnun vegar. Eftir greiningu gagnanna, flokkun þeirra og skýrslugerð er hægt að setja verstu kaflana í sérstakan flokk er varðar viðhald afvötnunar sem hægt er að nota í viðhaldssamningum. Hægt er að framkvæma afvötnunargreiningu á bundnu- sem og malarslitlagi. Niðurstöður athugana eru öruggar og endurtakanlegar og gera mönnum kleift að fylgjast með ástandi afvötnunar vegakerfisins.

Kynningarverkefni á ROADEX greiningaraðferðinni var framkvæmt á Íslandi á nokkrum vegum með bundnu slitlagi sem valdir voru af Vegagerðinni. Heildarlengd vega sem teknir voru til skoðunar var um 175 kílómetrar.

Afvötnunargreiningin sýndi fram á að ástand afvötnunar, á þeim vegum sem skoðaðir voru, var mun betra en í öðrum ROADEX aðildarlöndum þar sem sambærileg greining hafði farið fram. Aðalástæða þessa er að landslag og aðstæður á Íslandi er mjög frábrugðnar hinum ROADEX svæðunum. Yfirborð er yfirleitt frekar þurrt og stór hluti þeirra vega sem skoðaðir voru lágu um sléttlendi. Meirihluti veganna var byggður á fyllingu, á meðan í hinum ROADEX löndunum hefur stærstur hluti verið staðsettur í hliðarhalla.

Helstu erfiðleikarnir sem upp komu í greiningu voru að hrýfimælingagögn voru nokkuð við aldur, að mestu frá 2008, og upplýsingar um hjólfaramyndun voru ekki fáanlegar.

Gögnum var safnað með laser skanna um leið og afvötnunarathugun fór fram til þess að prófa dýptarreikning á skurðum á nokkru völdum köflum við íslenskar aðstæður, og til þess að fylgjast með yfirborði vegarins. Þessar mælingar sýndu fram á að ekki er hægt að reikna dýpi skurða út frá gögnunum þar sem skurðir eru yfirleitt staðsettir það langt frá vegi. Nokkuð merkileg gögn af vegyfirborði komu þó út úr laser skannanum.

LYKILORÐ

Afvötnun, greining, öxl, slitlag, líftími, hjólfaramyndun, IRI, laser skanni.

INNGANGUR

Athuganir á vegunum á Íslandi voru framkvæmdar í byrjun júní 2011 af fyrirtækinu Roadscanners Oy. Markmiðið var að kynna og prófa ROADEX afvötnunargreininguna og leiðbeiningar á hluta íslenska vegakerfisins.

Mælingarnar voru framkvæmdar af Seppo Tuisku frá Roadscanners Oy með aðstoð Vegagerðarinnar. Sverrir Ö. Sverrisson aðstoðaði við mælingarnar og gagnaöflun.

Úrvinnsla og greining mæligagnanna var í höndum Seppo Tuisku með aðstoð Sami Tuisku. Skýrslan sem hér gefur að líta var skrifuð af Seppo Tuisku og Annele Matintupa. Timo Saarenpää og Pekka Maijala frá Roadscanners Oy aðstoðuðu við meðhöndlun IRI gagna sem Vegagerðin útvegaði. Timo Saarenketo stýrði kynningarverkefnunum sem aðalstjórnandi ROADEX D1 „Hópur um viðhald afvötnunar". Ron Munro aðstoðaði við uppsetningu kynningarverkefnanna og las próförk. Mika Pyhähuhta frá Laboratorio Uleåborg hannaði útlit skýrslunnar.

Öll vinna í verkefninu var unnin í nánu samstarfi við starfsmenn Vegagerðarinnar. Án þeirrar hjálpar og aðstoðar hefði ekki verið unnt að ljúka þessu verkefni. Höfundar vilja sérstaklega þakka Haraldi Sigursteinssyni fyrir aðstoðina. Að lokum vilja höfundar þakka stýrinefnd ROADEX IV verkefnisins fyrir leiðbeiningar og hvatningu við vinnuna.

NIÐURSTÖÐUR, kafli 7 í skýrslu

Í heildina litið var ástand afvötnunar þeirra vega sem skoðaðir voru gott eða mjög gott. Yfir 79% þeirrar vegalengdar sem skoðuð var lenti í afvötnunarflokki 1. Algengasta var að vegir væru byggðir á fyllingu, allt í allt var 57% vegalengdarinnar af þeirri tegund. Var þetta mjög frábrugðið frá vegum sem teknir höfðu verið til skoðunar á öðrum ROADEX svæðum.

Eins og áður hefur verið minnst á voru einu hrýfigögnin fyrir þá vegi sem skoðaðir voru gögn sem sýndu meðaltal 20 metra kafla. Niðurstöður greiningarinnar sýndi fram á að ágallar í afvötnun samsvöruðust ekki hrýfigögnunum. Að hluta til mætti skýra það með aldri hrýfigagnanna.

Á norðurlöndunum er litið á gras/gróður á öxlum sem óæskilegan þátt sem ætti að fjarlægja. Þau ROADEX afvötnunar kynningarverkefni sem áður hafa farið fram hafa sýnt fram á sterk tengsl milli hrýfis vegar og upphækkaðra grasaxla. Á Íslandi sýndi tölfræðigreiningin ekki fram á þessa samsvörun. Tölfræðilegt hrýfi var það sama hvort sem um gróður var að ræða á öxlum eður ei.

Sums staðar voru frárennslisskurðir ekki að virka á nógu skilvirkan hátt. Vatn stóð í þeim og gróður var áberandi í sumum frárennslisskurðum. Að mestu leyti var þetta vegna flatlendis og af þeirri ástæðu gæti verið erfitt að ná fram endurbótum.

Á síðustu árum hafa mestu framfarir í athugunaraðferðum átt sér stað með notkun laser skanna. Óhjákvæmilegt er að slík tæki verði staðalbúnaður í ýmsum viðahaldstjórnunarverkefnum á vegum. Í verkefninu á Íslandi sýndi laser skanninn fram á áhugaverðar breytingar á vegyfirborði sem mannsaugað gat ekki greint. Gögnin úr skannanum sýndu einnig fram á vegkafla þar sem aflögun var í öxl vegarins. Aðeins einn vegkafli var prófaður með skurðadýptarútreikningum þar sem oftast voru skurðir það langt frá vegi að ekki var hægt að nota slíka útreikninga. Þar sem hægt var að nota útreikningana tókst það og niðurstöður þeirra voru í samræmi við önnur kynningarverkefni þar sem aðferðin hefur verið prófuð áður.

Afvötnunargreiningin á þeim köflum sem skoðaðir voru á Íslandi sýndi fram á nokkra vegkafla sem bjuggu við ágalla í afvötnun, þó að þessi ágallar hefðu minniháttar áhrif á ástand vegarins. Mælt er með að afvötnun þessara vega verði bætt og þannig komið í veg fyrir möguleg vandamál í framtíðinni.

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 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 Iceland were carried out on several paved roads selected by Icelandic Road Administration. The total length of the roads analyzed was approximately 175 kilometres.

The drainage analysis revealed that the drainage condition on the surveyed roads was clearly better than the other ROADEX countries surveyed. The main reason for this was the terrain which is quite different in Iceland than in other ROADEX areas. The terrain in Iceland is quite dry and a large part of the surveyed chainage was on even ground. The majority of the roads surveyed were constructed on embankments, while in other ROADEX countries the greatest proportion have been located on side sloping ground.

The challenge for the Icelandic drainage analysis was that the profilometer data supplied was quite old, mainly from 2008, and that rutting data was not available.

Laser scanner information was also collected at the same time as the drainage surveys to test the depth calculation of ditches on some selected sections in Icelandic conditions, and to monitor the pavement surface. These laser scanner measurements showed that it was not possible to calculate the depth of the ditches as the ditches were located too far from the road. Some interesting crown section observations were however able to be made from the laser scanner data.

KEYWORDS

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

PREFACE

The drainage analysis field surveys in Iceland were carried out in the beginning of June 2011 by Roadscanners Oy. The goal was to demonstrate the ROADEX drainage analysis technique and guidelines on the Icelandic road network.

The field measurements were carried out by Seppo Tuisku of Roadscanners Oy with the help of the Icelandic Road Administration (Vegagerdin). Sverrir Sverrirsson of the Icelandic Road Administration 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 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 done in close cooperation with personnel from the Icelandic Road Administration (Vegagerdin). Without their help and support it would not have been possible to complete the work. The authors would especially like to thank and acknowledge the assistance given by Haraldur Sigursteinsson of the Icelandic Road Administration.

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 Roads 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 Iceland.

2. ROADS SURVEYED

The drainage analysis surveys of this report were carried out on selected sections on 10 different roads. The roads and sections surveyed were selected by Icelandic Road Administration. The detailed section information is presented in Table 1 and they are shown in the map in Figure 2. The sections surveyed were:

- Four sections on road 1. Sections B7, B5 and B4 were southeast from Reykjavik and section G8 was north from Reykjavik.
- The first two sections of road 26 starting from the road 1.
- The first sections of roads 31, 32, 37 and 38.
- Section 8 of the road 35 and section 2 of the road 51.
- Five consecutive sections of road 36 northeast from Reykjavik starting from section 12.
- Sections 2 and 3 of road 54 north from Reykjavik.

Table 1. The surveyed road sections in Iceland, their lengths, start and end points

ROAD	SECTION	ROAD NAME	START POINT	END POINT	LENGTH (m)
1	b4	Hringvegur	Vík, Mýrarvegur, skurður t.v.	Dyrhólavegur (218-01)	12070
1	b5	Hringvegur	Dyrhólavegur (218-01)	Pétursey (219-01)	5760
1	b7	Hringvegur	Raufarfellsvegur (242-01) vestri endi	Sandhólmavegur (247-01) eystri endi	13100
1	g8	Hringvegur	Snæfellsnesvegur (54-02)	Hvítárvallavegur (510-01)	8600
26	01	Landvegur	Hringvegur	Hagabraut (286-02) nyrðri endi	8980
26	02	Landvegur	Hagabraut (286-02) nyrðri endi	Múli	13930
31	01	Skálholtsvegur	Skeiðavegur (30-03)	Hvítá	9530
32	01	Þjórsárdalsvegur	Skeiðavegur (30-04)	Stóra-Núpsvegur (328-01)	12810
35	08	Biskupstungnabraut	Laugarvatnsvegur (37-04)	Hrunamannavegur (30-08)	8830
36	06	Þingvallavegur	Haksvegur	Grafningvegur efri (360)	6820
36	07	Þingvallavegur	Grafningvegur efri (360)	Kjósarskarðsvegur (48)	5100
36	08	Þingvallavegur	Kjósarskarðsvegur (48)	Sýslumörk	2240
36	11	Þingvallavegur	Sýslumörk	Skeggjastaðir	7990
36	12	Þingvallavegur	Skeggjastaðir	Hringvegur	7190
37	01	Laugarvatnsvegur	Biskupstungnabraut (35-04)	Lyngdalsheiðarvegur (365-01)	12230
38	01	Þorlákshafnarvegur	Hringvegur (1-d8)	Þrengslavegur (39-01)	11600
51	02	Akrafjallsvegur	Akranesvegur (509-01)	Hringvegur (1-g2)	11240
54	02	Snæfellsnesvegur	Hringvegur (1-g8)	Álftaneshreppsvegur (533-03)	12060
54	03	Snæfellsnesvegur	Álftártunguvegur (5375-01)	Hítardalsvegur (539-01)	4720
				Total	**174 800**

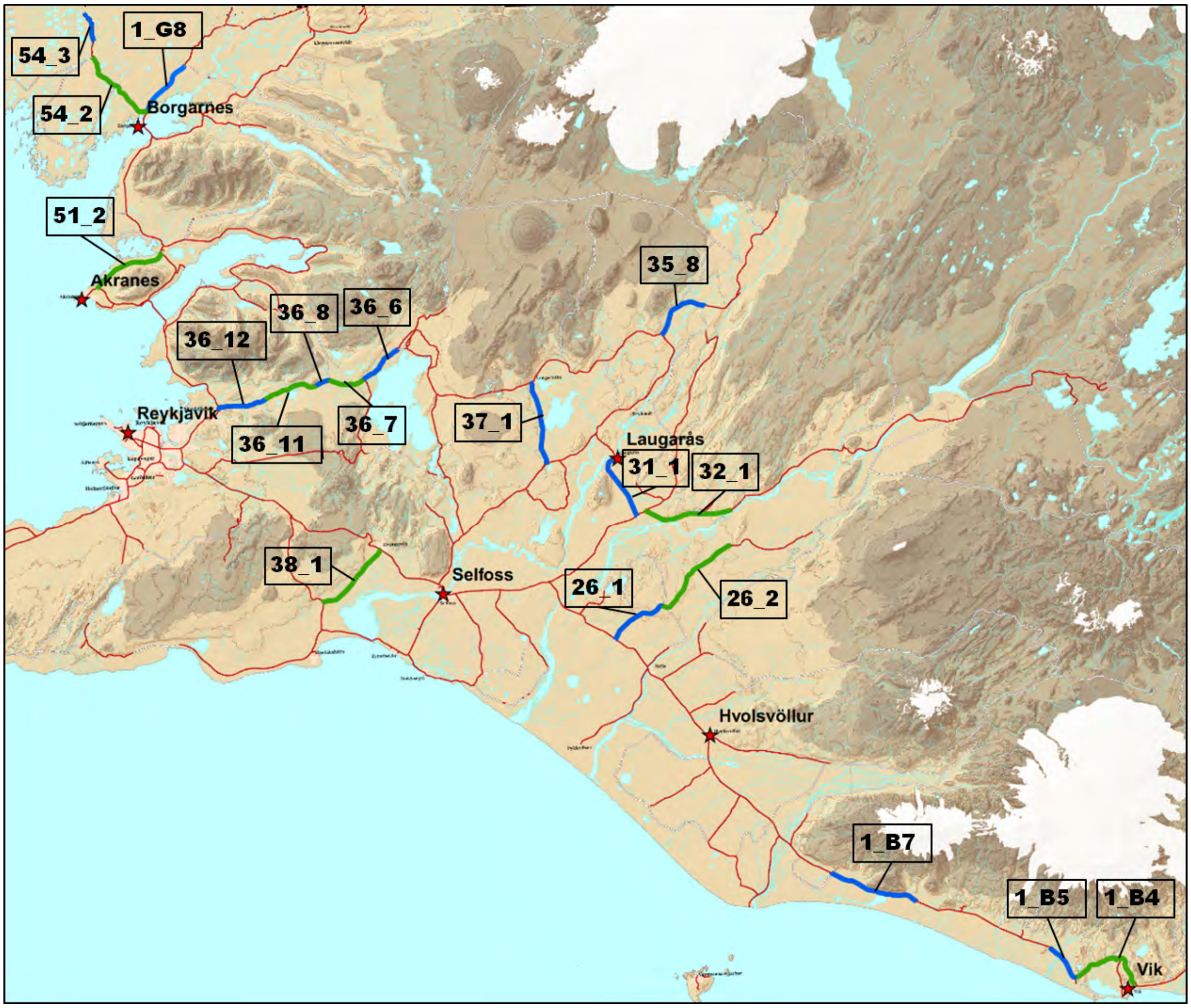

Figure 2: The surveyed road sections in the Iceland demonstration project.

All of the surveyed road sections in this ROADEX drainage survey were paved roads. Road 1 (the ring road) connects the most populous parts of the country and in all the surveyed sections the traffic was quite busy. On the rest of the surveyed roads the volume of traffic varied and for the most part they had noticeably less traffic.

3. DATA COLLECTION, FIELD SURVEYS

3.1. GENERAL

The data collection for the demonstration project was carried out in the beginning of June 2011. As already mentioned the sections for the survey were selected by the Icelandic Road Administration (ICERA). All of the roads surveyed were local to Reykjavik and the survey team operated out of Reykjavik for the duration of the work.

After installation and testing of the survey equipment the drainage surveys started from road 36, the closest road to survey. The surveys continued over the following days southeast from Reykjavik on roads 1, 26, 31, 32, 35, 37 and 38. The last surveyed road sections on roads 51, 54 and one section of the road 1 (section G8) were located north from Reykjavik.

The total length of surveyed roads was approximately 175 kilometres. All roads were paved roads. For the most part the weather during the surveys was dry and windy though a few local showers occurred on southeast part of the survey.

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 the Icelandic Road Administration and is shown on 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 onboard 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. The digital video cameras used in this project were provided by The Imaging Source.

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. The laser scanner can also be seen in this photograph at height of 3m behind the vehicle.

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 laptop 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. A second laptop was used to collect the laser scanner data (Figure 4).

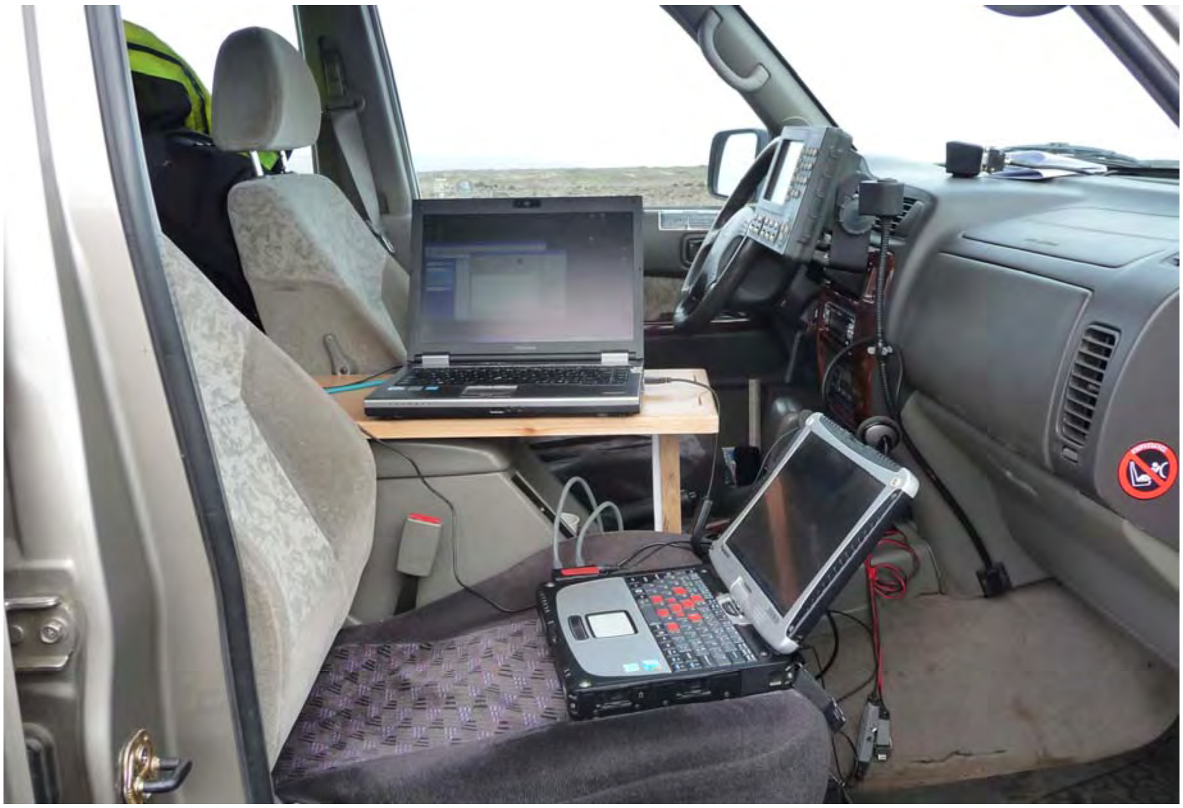

Figure 4: A Toughbook laptop (front) was used for drainage analysis. Red pieces of tape helped to choose the right keys during the survey. A second laptop (back) was used to collect the laser scanner data.

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 the laser scanner technique 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

4.1. GENERAL

Road drainage conditions in Iceland differed significantly from the drainage conditions in other Nordic countries. The most significant difference was the location of the roadside ditches. In other Nordic countries where the ROADEX drainage analysis has been largely used in recent years the ditches are normally placed close the roadside. In Iceland the ditches were placed far from the road and in many cases there were also horse tracks between the road and the ditches.

Another major difference was the large amount of dry terrain where the drainage in normal weather conditions is not a problem. Also the landscape was open and treeless.

In some sections the variations of elevation were significant while the amount of flat terrain road sections was also conspicuous. In flat areas the water flow in the roadside ditches was slow and in many sequences there was significantly amounts of standing water.

There were no constructed verges on the Iceland road network but some road sections were identified where verges had developed naturally. Where these occurred they were causing the same problems as those found in earlier ROADEX projects, i.e. restricting water flow away from the pavement, and resulting in ponding and other problems.

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. 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 Icelandic road network.

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 Icelandic road network.

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 ponding on the traffic lane or on the shoulder. Vegetation is growing in the ditches and restraining the flow of water creating dams in the ditches. Unstable soil is flowing from ditch slopes into the bottoms of ditches and blocking the flow of water. Clogged culverts or outlet ditches is preventing the flow of water 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 Icelandic road network.

4.3. VERGE CLASSIFICATION

In this ROADEX drainage demonstration project in Iceland 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 present 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. In Iceland the existing verges for the most part were low. Examples of verge Class 2 are shown 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 SURVEY

Laser scanner surveys in drainage analysis have been previously tested in several ROADEX projects with promising results. The aim of the laser scanner surveys in Iceland was to test the laser scanner drainage survey method in Icelandic road conditions.

The data from the laser scanner surveys was processed with the Road Doctor Laser Scanner (RDLS) module. According to the guidelines in the Nordic countries the bottom of the ditch should be at least 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.

4.4.1. Ditch depth analysis

The depth of the 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 ditch depth information to the analysis view.

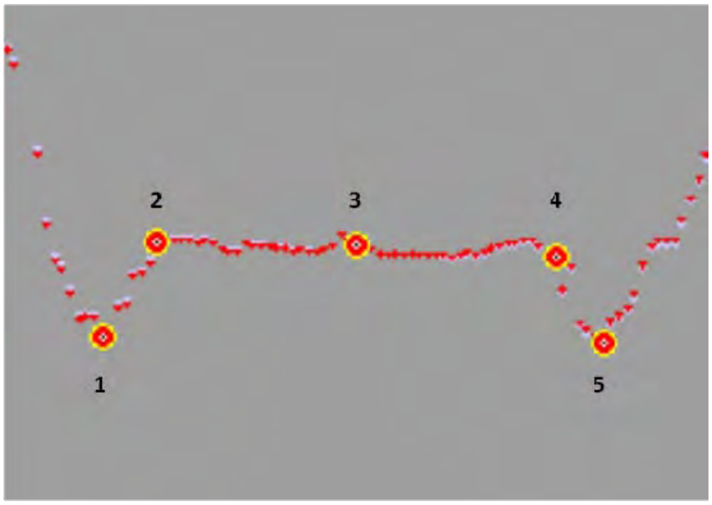

Figure 11: Diagram showing the points selected from the cross-section, from left to right: 1.The bottom of the left ditch 2.left road edge 3.centreline 4.right road edge 5.the bottom of the right ditch

4.4.2. Surface maps

Changes in the surface topography of a pavement, compared to its 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 discern visually.

The use of a “rainbow map” however makes it considerably easier to visualize these deviations. These maps show road surface topography and its deviations and damage. Figure 12 presents an example of a rainbow map where each colour in rainbow colour palette scale represents a 40 mm change in surface level.

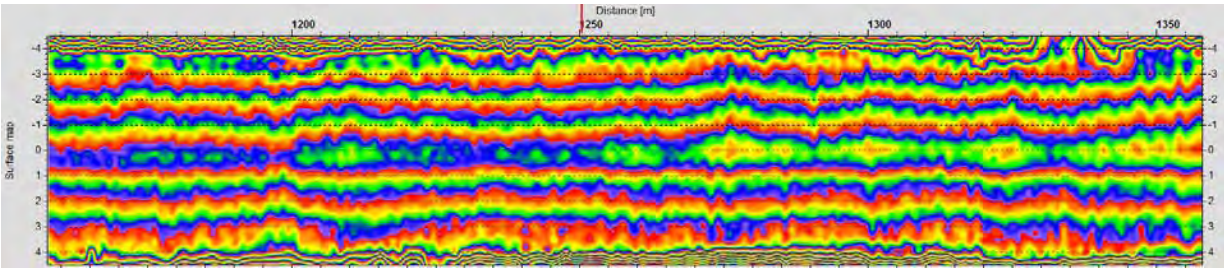

Figure 12: A rainbow map of a road section, which has a good crown section. Each complete colour palette represents 40mm change in surface level relative to the centreline.

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 1

5.1.1. Section B4

Section B4 of road 1 was surveyed from the village of Vik to the junction of road 218, a length of 12070m. The first 2 kilometres of the road was on a hillside and the elevation variations were significant. The prevailing road profile on this section was embankment (49%) and the drainage was in good condition. Nearly 91% of the chainage the drainage was classified as Class 1. Some minor drainage deficiencies were found and examples are shown in Figures 13-15.

Figures 13: Footway kerb blocking water flow causing minor washout damages. Chainage on the left figure is from 10m, and on the right 30m.

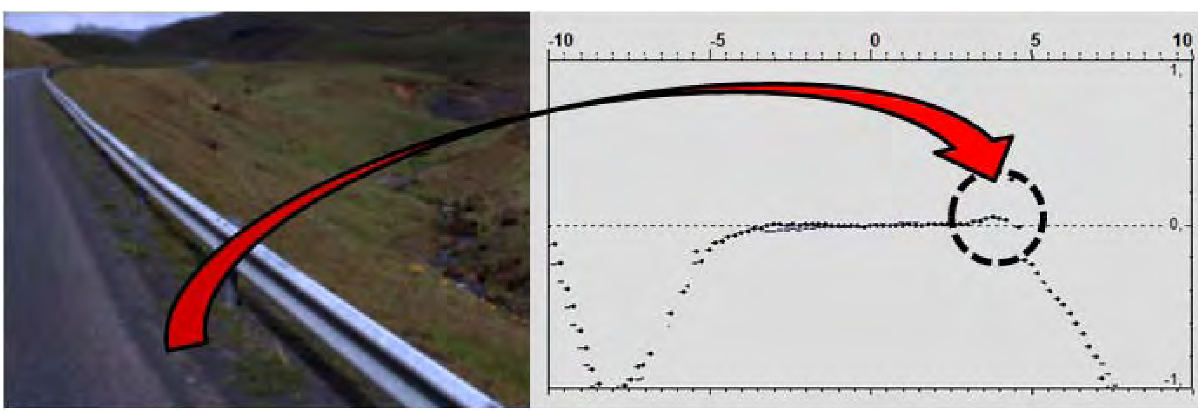

Figure 14: Verge under the guardrail, chainage 720m

Figure 15: Minor drainage deficiencies on a curve. The ditch was placed far from the road behind the horse track (9480m).

Figure 16 shows an example rainbow map of a section of road B4 which has generally a well shaped crown section.

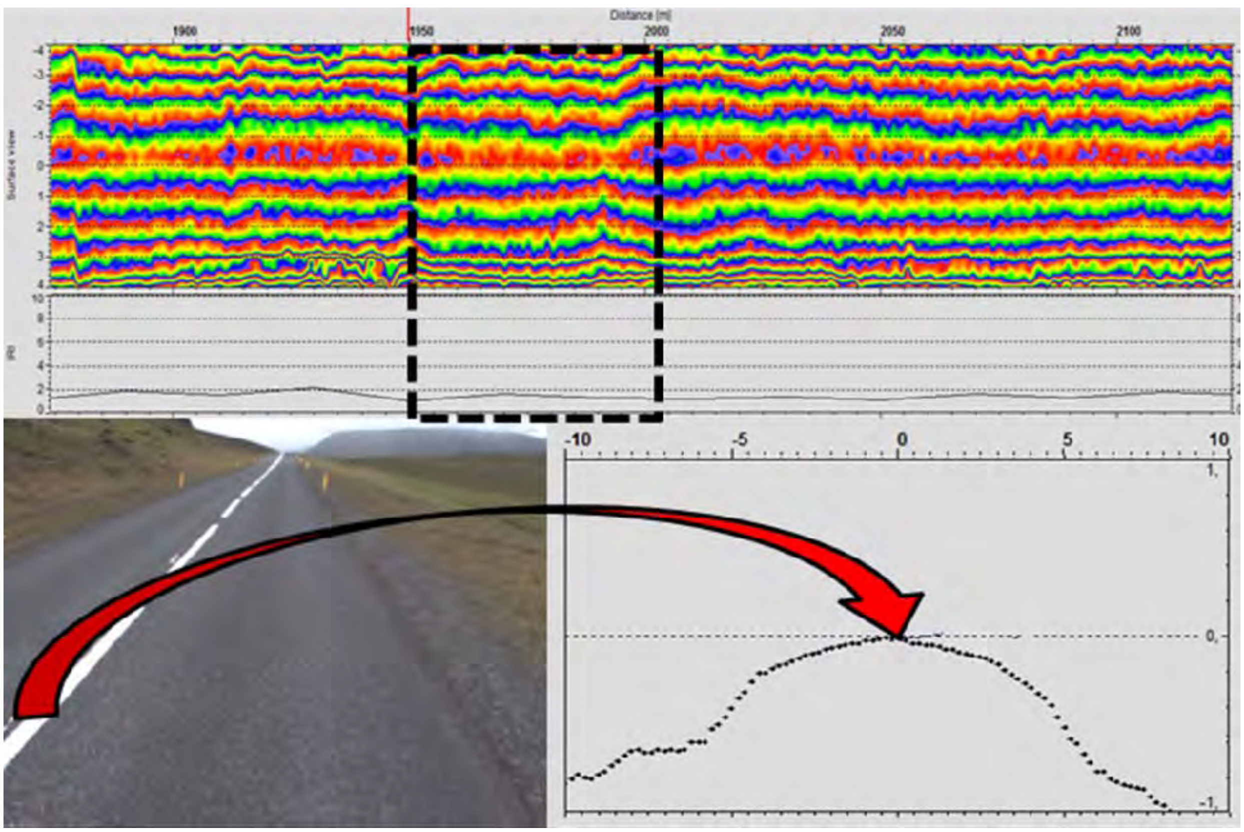

Figure 16: Road section with low IRI (2mm) values and a good crown section as seen from the rainbow map (black dotted line) and from the cross section picture (Chainage 1950m).

5.1.2. Section B5

Section B5 of road 1 continued from the junction of road 218 to the junction of road 219, a length of 5760m. The drainage was in good condition, the few existing deficiencies noted were typical for the Icelandic drainage conditions and were related to the ditches which at times were located too far from the road to take care of the drainage in an efficient way. In some sections the verge was hindering the water flow from the pavement surface and causing ponding (Figure 17).

Figure 17: Verge is stopping the water on the edge of the pavement, chainage 3830m.

5.1.3. Section B7

Section B7 of road 1 was measured from the junction of road 242 to the junction of road 247, a section length of 13100m. Ash remains from the 2010 eruption were visible at the beginning of the section but mostly the ditches were clean and the drainage was working efficiently (Figures 18).

Figures 18: Volcanic ash from the eruption was still visible in the ditches (at chainages 130m and 480m)

Within section B7 there were several lengths where verges were slowing the water flow from the pavement surface to the ditches. At times the ditches were shallow, and the vegetation growing on the road shoulder was hindering the water flow (Figures 19-20).

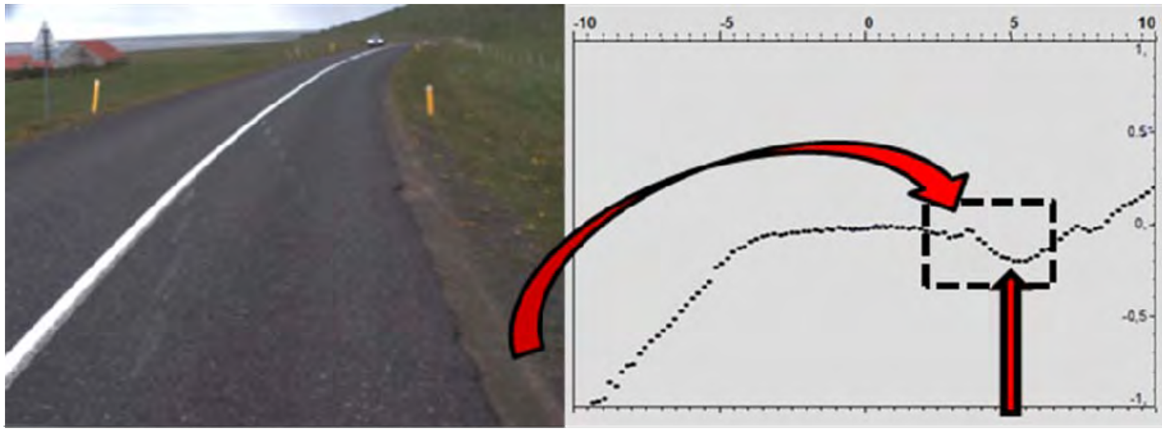

Figure 19: Shallow ditch and verge on the upper side of the side sloping road profile (3520m).

Figure 20: Shallow ditches and verge causing the water to infiltrate into the edge of the pavement (Chainage 2620m and 5700m).

5.1.4. Section G8

Section G8 on road 1 was surveyed from road 54 to the junction of road 510, a section length of 8600m. The first 3 kilometres of the section were on “even ground”, and later the road was on embankment for the most part.

The rainbow map and the cross section data in Figure 21 show that the crown section was in generally good shape but that the road shoulders were somewhat elevated (possibly because of road widening). The ditches were located far from the road and the drainage was not working perfectly, but the IRI data did not show higher values compared to the later part of the section which was on embankment for the most part.

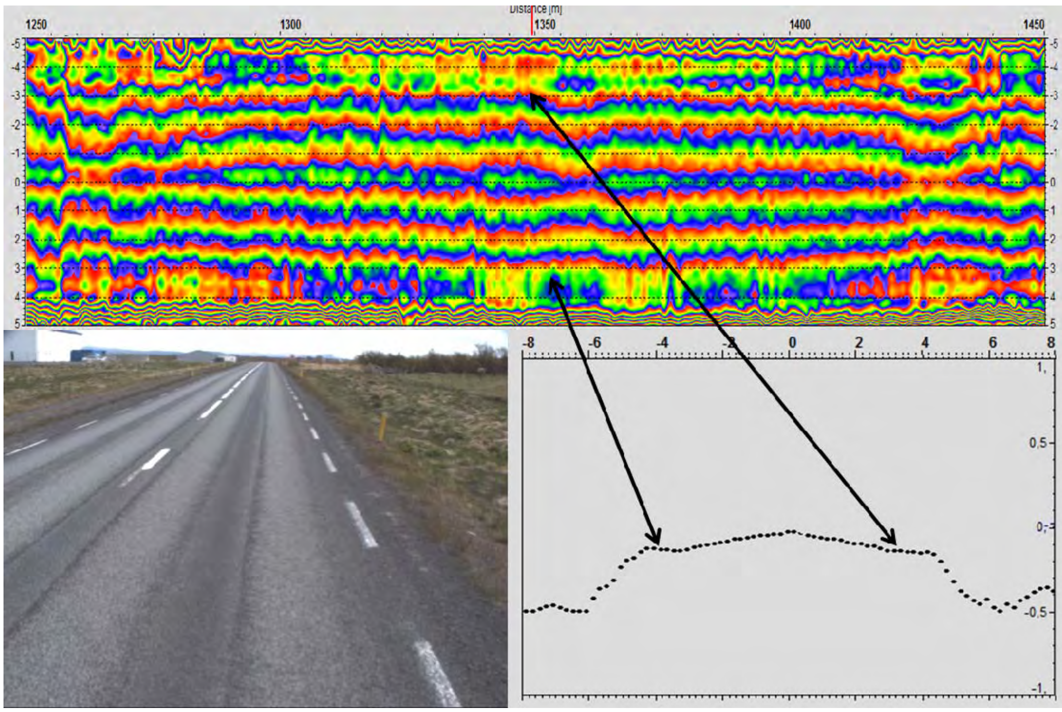

Figure 21: Strong elevated road shoulders at chainage 1350m.

From chainage 6700m to 7000m the ditch on the right was full of water and vegetation but this did not seem to have any impact on the road. The IRI values in this particular section were not higher than the rest of the section (Figure 22).

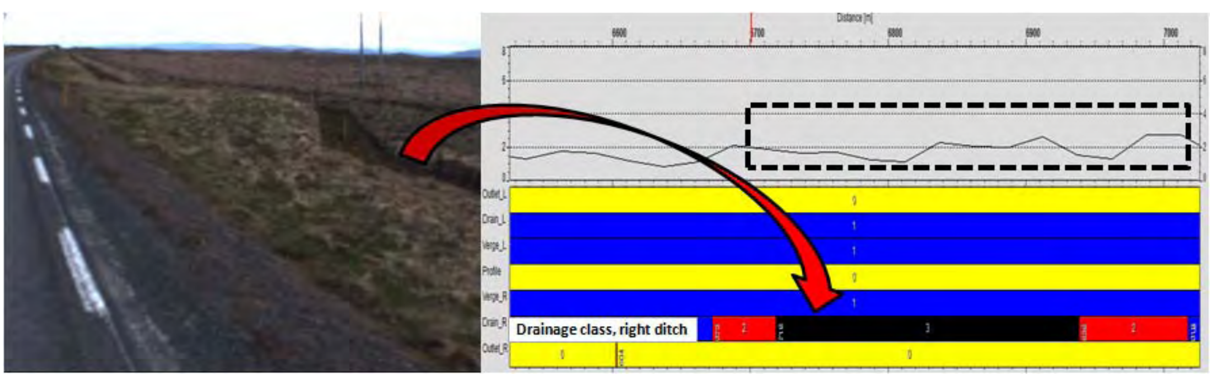

Figure 22: Drainage is Class 3 but no change in IRI values, chainage 6700m.

5.2. ROAD 26

5.2.1. Road 26 Section 1

The survey of the first section on road 26 started from road 1 and ended at the junction with road 286, a section length of 8980m. The road profile was mostly side sloping (50%) and the drainage was in adequate condition, nearly 69% of the chainage was classified as drainage Class 2. Despite this large percentage of drainage Class 2 only less than 1% of the chainage was classified as drainage Class 3 which meant that no severe drainage deficiencies were found on this section.

Verges were however preventing the water flow to the ditches at times (Figures 23-24) especially in the middle part of the surveyed section. The laser scanner cross section view (Figure 25) from chainage 2640m shows how the verge was clearly blocking the water flow.

Figure 23: Verge hindering the water flow from the pavement surface (chainage 2850m, 3920m).

Figure 24: Problematic verge at chainage 4270m and 8830m.

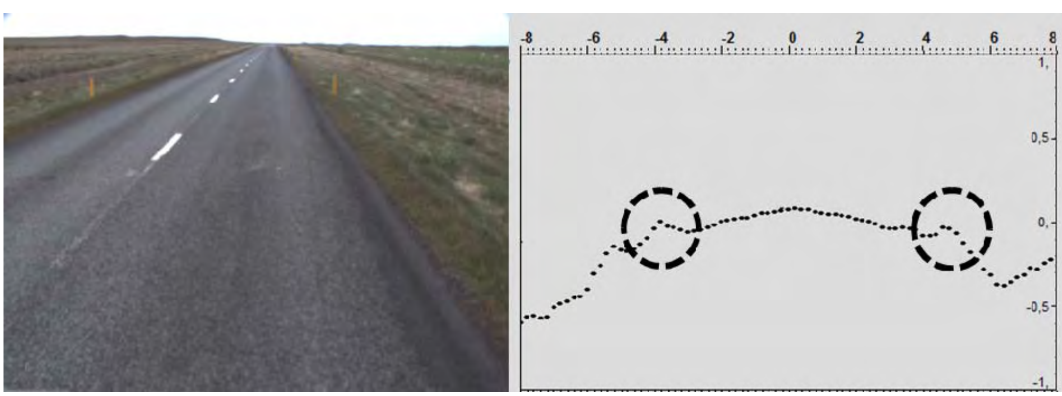

Figure 25: Verges on cross section view, chainage is 2650m.

5.2.2. Road 26 Section 2

Section 2 of road 26 started from the junction with road 286 and ended at a junction at chainage 13930m, a length od 13930m. The drainage condition was excellent on this section; no less than 91% of the chainage was classified as drainage Class 1. The terrain was particularly dry at the end of the section. The prevailing road profile was embankment; about 71% of the chainage was on embankment.

A substantial quantity of water was standing in the left roadside ditch at chainage 2700m most likely due to the ineffective outlet ditch. The terrain was flat and the water in the outlet ditch did not have a natural flow. At the time of the survey time this ditch was full of vegetation and water (Figure 26).

From chainage 6300m to 6500m there was a similar section where the water did not have proper exit way from the roadside ditch (Figures 27). On that location the measured IRI values (marked with the black dotted box) were slightly higher than the surrounding IRI values (Figure 28).

Figure 26: Outlet ditch full of vegetation and water, chainage 2730m.

Figures 27: Water standing in the ditch behind the horse track, chainage 6300m-6500m.

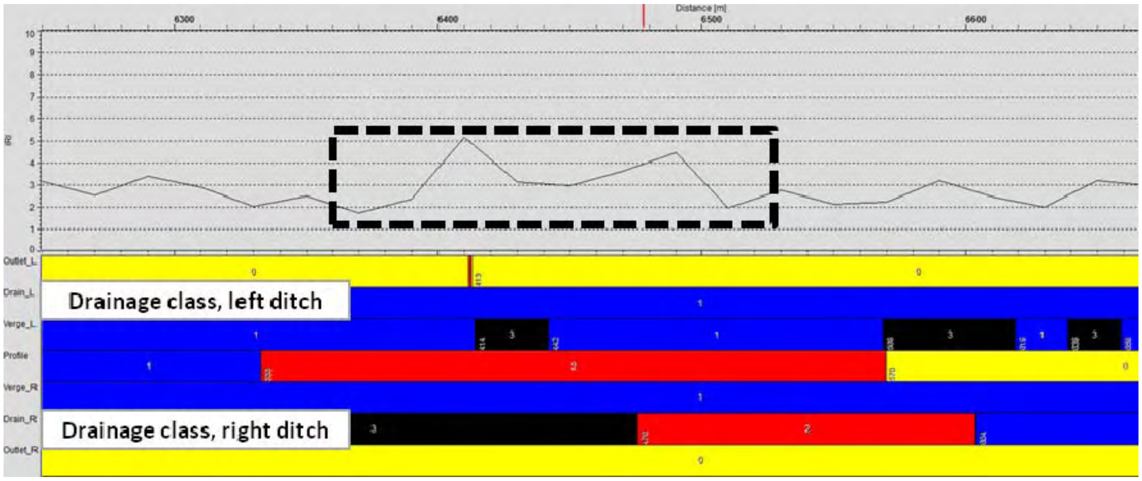

Figure 28: Higher IRI values at chainage 6400m-6500m, where water was standing in the ditch behind the horse track.

5.3. ROAD 31 SECTION 1

The surveyed section of the road 31 started from the road 30 intersection and ended after the bridge over the Hvita River, a length of 5930m. The drainage was in good condition on this section. For the most part this section was on embankment (80%) and because of the higher road structure the few existing drainage deficiencies did not have a major impact on the pavement condition. Approximately 76% of the chainage was classified as drainage Class 1.

On section 1 there were only a few lengths where the drainage condition might need some attention. In most of these cases the verge should be removed (Figure 29), but in the last part of the section some of the ditches would work better if they were cleaned also (Figure 30).

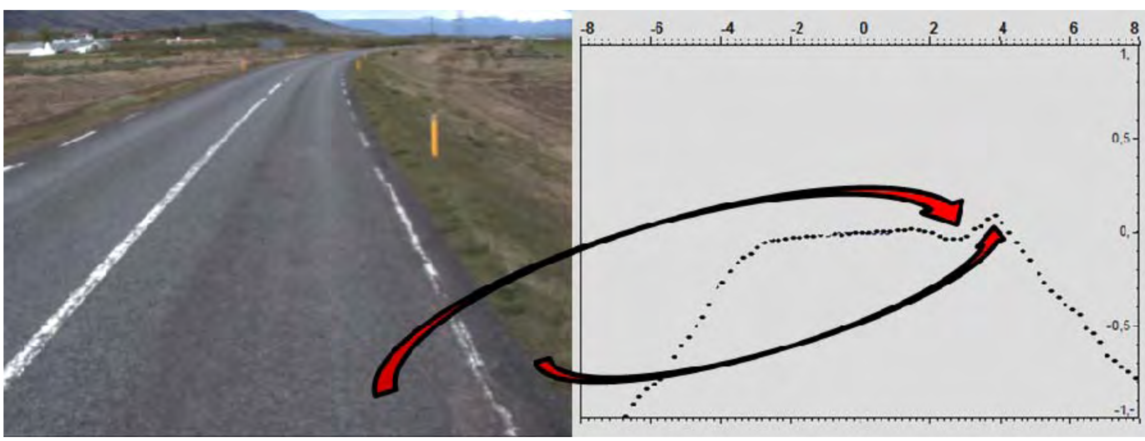

Figure 29: Deformation in the laser scanner cross section view at chainage 60m.

Figures 30: Inadequate drainage on the upper side of the side sloping profile. Left figure is the road camera view and the right figure is the ditch camera view, chainage 8810m.

5.4. ROAD 32 SECTION 1

Surveys on road 32 started from the road 30 and ended at the junction with road 328, a length of 12810m. Statistically the drainage was in excellent condition on this section; more than 92% of the chainage was in drainage Class 1.

From 850m to 1100m the ditch on the left side was full of water and vegetation. The roadside ditch itself was deep but the water did not seem to have an exit way (Figure 31). Another short length with the same kind of drainage problem where water stayed on the upper side of the side sloping road profile was located at 6800m to 6900m.

The terrain in the last half of the section was particularly dry and there were no drainage problems, only couple of short sections with a verge (Figure 32).

Figure 31: Water stays in the ditch on the left side, left figure is the road camera view and the right figure is the ditch camera view (chainage 1090m from direction 2).

Figure 32: Verge preventing the water flow, chainage 6520m and 6760m.

5.5. ROAD 35 SECTION 8

The survey on road 35 section 8 started from the junction of road 37 and ended at the junction of the road 30, a length of 8830m. In the beginning the terrain was dry and the few existing drainage deficiencies were verge related. Figure 33 shows an example of how shoulder deformation can occur due to verges and road widening. On the left side from chainage 2200m to 2500m water was standing in the ditch and the verge was blocking water flowing off the road. The ditch slopes had partly slipped to the ditch and the vegetation was hindering the water flow (Figure 34). Verge problems continued at times along the section until the start of the upgraded part of the section at 7090m chainage. The rest of the section was on embankment and the drainage was in excellent condition.

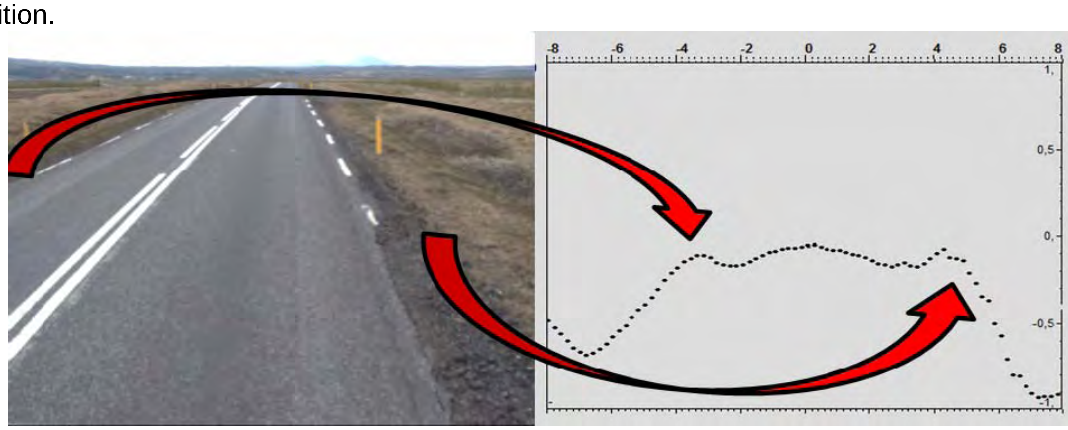

Figure 33: Shoulder deformation on both sides of the road (chainage 240m).

Figure 34: Water is standing in the ditch bottom, the left figure is the road camera view and the right figure is the ditch camera view at the same chainage (chainage 2290m).

5.6. ROAD 36

5.6.1. Section 06

Section 06 of road 36 was surveyed from the junction of Almannagja to the junction of the road 360, a length of 6820m. The section had been upgraded and the drainage was in excellent condition.

At chainage 4750m a verge that had formed under the guardrail was hindering the water flow to the ditch (Figure 35).

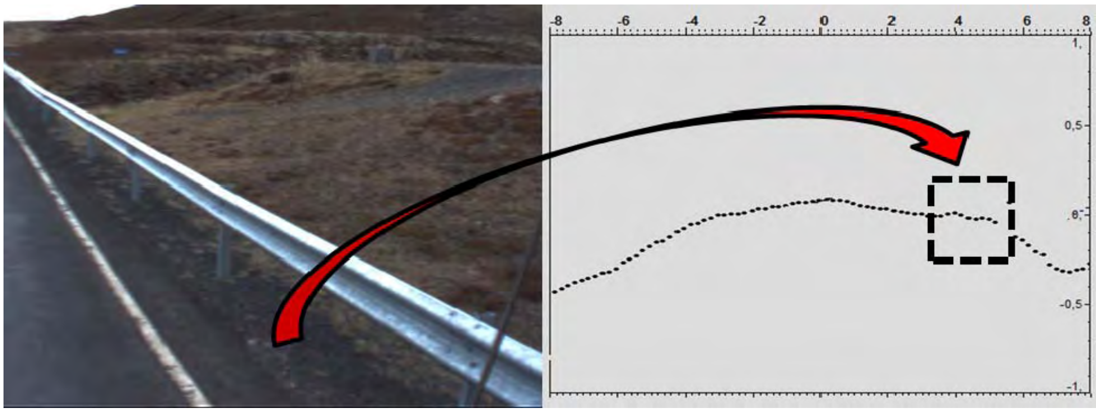

Figure 35: Minor deformation under the guardrail at 4750m.

5.6.2. Section 07

Section 07 of road 36 was surveyed from the junction of road 360 to the junction of road 48, a length of 5100m. For the most part the terrain along the section was dry. The pavement condition varied (Figures 36) along the section but the drainage was in excellent condition.

Figure 36: In road 36 section 07 the pavement condition varied but there were no drainage problems (chainage left 600m, right 2700m).

5.6.3. Section 08

Section 08 of road 36 was a short section (2240m) which commenced from the junction of road 48. Dry terrain continued on this section and no severe drainage deficiencies were found. Within the section there were three similar lengths where water was standing in the ditch. On all of these sections the road was on high embankment and the water in the ditches did not seem to affect the road condition (Figures 37). A couple of short lengths with minor verges were also found especially in the beginning of the section.

Figure 37: Water standing in the ditches in section 08 but the road is on high embankment, chainage from left to right: 650m, 1120m and 1410m.

5.6.4. Section 11

Section 11 of road 36 continued from the end of the previous 08 section. The length of the section was 7990m. In the right ditch there were a few lengths where unstable material had partly filled the ditch (Figures 38) and this was clearly hindering the water flow. Cleaning of the ditches could be problematic however as the local soil type is peat. These drainage deficiencies did not seem to have an effect on the visual road pavement condition. IRI data was not available for this section.

On the left side of the section from 4500m to 5600m the road was on a side sloping road profile and the left side was the upper side. The ditch was more or less filled with collapsed material from the ditch walls resulting in standing water in the ditch. Normally this kind of drainage defect would have caused consequential problems for the road, but on this section this was not apparent (Figure 39). One reason could have been that even though there was water standing in the ditch, the level of water in relation to the road structure was low, and also there were several culverts which seemed to work well. Verges were not a problem on this section.

Figure 38: Unstable material was hindering water flow in the ditch (chainage 480m and 890m)

Figure 39: Collapsed ditch walls on the upper side of the road profile at 4690m and 5450m.

5.6.5. Section 12

Section 12 of road 36 was surveyed from the end point of section 11 to the roundabout at road 1, a length of 7190m and the prevailing road profile on the section was side sloping ground (52.5%). The drainage was working mainly well on this section. In the middle part there was a section (3700m- 4900m) where the right ditch was shallow and filled with vegetation, but this had not affected the visual condition of the road. IRI data was not available for this road section. The side sloping cross profile became steeper near the end of the section and the drainage system was insufficient in the upper side of the slope (Figure 40).

Figures 40: Insufficient drainage on the upper side of the steep side slope at chainage 6900m. The left is the road camera video and the right is the ditch camera video.

5.7. ROAD 37 SECTION 1

The only surveyed section on road 37 started from road 35 and ended at the roundabout with road 365. The length of the section was 12230m. Drainage was in good condition in this section, nearly 86% of the chainage was classified as drainage Class 1. In some sections verges were hindering water flowing off the road surface at times (Figure 41). At chainage 8000m on the left there was a short section with some water between the horse track and the roadside. The ditch was behind the horse track (Figure 42). Near the section end on the left the ditch was full of water and vegetation and collapsed ditch walls had partly filled the ditch (Figure 43).

Figure 41: Examples of verge, chainage 8450m (left) and 10640m (right).

Figures 42: Water lying between the road and the horse track (chainage 7990m, 8010m).

Figures 43: Ditch filled with vegetation and water. Left figure is the road camera view and the right figure is the ditch camera view, chainage 11480m.

5.8. ROAD 38 SECTION 1

Road 38 survey started from the roundabout where the road 38 begins. The length of the section was 11600m and the section ended at its junction with road 39. Statistically the drainage was in excellent condition, more than 93% of the road was in drainage Class 1. The terrain was extremely dry, especially in the end part of the section (Figure 44).


Figure 44: Dry terrain in the end part of the section (chainage 9900m (left), 11000m (right)).

The few drainage shortages found were due to the presence of verges (Figure 45). On the right side from 3300m to 3400m some bush clearing had been carried out and at the time of the survey there was still debris lying in the bottom of the ditch.


Figures 45: Verge was preventing the water flow from the pavement surface at times (chainage 4030m on the left, 11090m on the right).

5.9. ROAD 51 SECTION 2

Section 2 of road 51 was surveyed from Akranes junction to its junction with road 1. The length of the section was 11240m.

From chainage 4150m to 5050m, water was standing in the ditch mainly on the right side of the road (Figure 46). The terrain was generally flat in the area and the main problem was caused by outlet ditches which were not working properly (Figure 47). However improving these ditches could be challenging to find an outfall as the area is so flat. A horse track had been constructed between the ditch and the road and this could have actually helped the drainage condition for the road as it was keeping water further from the road than a normal roadside ditch. There were no extra damages in the pavement and the IRI was average for the section.

In the last part of the section the drainage was in good condition. Only few short sections of drainage defects and verges were found (Figures 48-49).

Figure 46: Ditch full of water and vegetation at chainage 4380m.

Figure 47: Blocked outlet ditch at chainage 4370m

Figure 48: Unstable material on the bottom of ditch was hindering the water flow (chainage left: 7850m, right: 7890m).

Figure 49: Minor verge at chainages 10220m and 10340m.

5.10. ROAD 54

5.10.1. Section 2

The survey of section 2 on road 54 started from the roundabout on road 1. The length of the section was 12060m and ended at the junction of road 533 to the left. Statistically this section was in very good drainage condition. Nearly 88% of the chainage was classified as drainage Class 1.

Within the section only a few lengths had minor drainage deficiencies and/or verges (Figures 50-51). Water was standing in the ditches from chainage 6750m to 7600m and this correlated well with the available IRI data (Figures 52-53). Improving the drainage on this section might be difficult however because of the flat terrain. The pond on the left which appeared to be at the same elevation may cause difficulties also.

Figure 50: Example figures of verge at chainage 1270m and 2690m.

Figure 51: Shallow ditch (upper arrow) and verge (lower arrow) in laser scanner cross section, chainage 5760m.

Figure 52: Water standing in the ditches (chainage left: 6760m, right: 7020m).

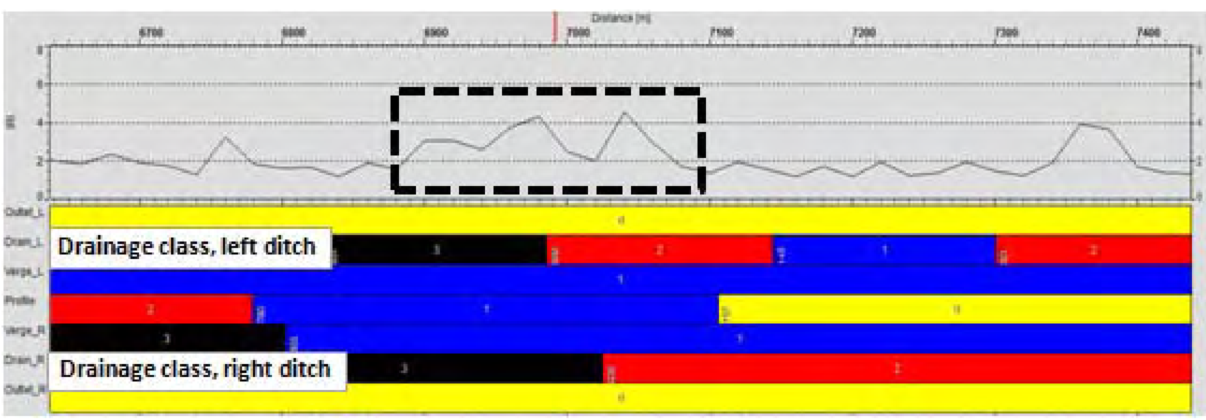

Figure 53: Higher values in the IRI data on the same section as shown in Figure 52.

5.10.2. Section 3

The survey of section 3 on road 54 started at the junction before the River Alfta and ended at the junction of road 539, a length of 4720m. From 1600m to 2300m the road was on 0-level road profile and the drainage was not functioning in the best possible way. On the right side there was standing water due to vegetation in the ditch hindering free water flow (Figure 54). In Iceland drainage deficiencies of this kind have, in many cases, little effect on road profilometer data or pavement distress. This was also the case on this length. No extra pavement damages were found, and the available IRI data was the same as anywhere else on the section.

Figures 54: Water and vegetation in the ditch, chainage 1740m. The left figure is the road camera view and the right figure is the ditch camera view.

6. STATISTICAL RESULTS OF THE SURVEY

6.1. SUMMARY OF THE ROADS

The distribution of the road profile on the roads surveyed in the Icelandic project was different to other ROADEX drainage demonstration projects. The prevailing road profile, by a clear margin, was embankment (57%) (Figure 55), while in other ROADEX drainage demonstration projects the prevailing road profile has been side sloping ground. The share of the side sloping ground road profile in other drainage projects has usually been about two thirds of the chainage while in Iceland it was only 23% of the chainage. The proportion of embankment in previous projects has varied from 3% in Scotland to 17% in Norway.

The average drainage class in the Iceland demonstration project was the best in road sections classified as embankment (Figure 56). This was a similar result to previous demonstration projects in other ROADEX areas. Road cuts and side sloping ground road profiles have statistically been the most problematic sections in other projects but in Iceland the most problematic road profile, with minor differences, seemed to be the 0-level road profile. Overall the proportion of the road cut road profile (only 1%) in Iceland was clearly the lowest of all projects.

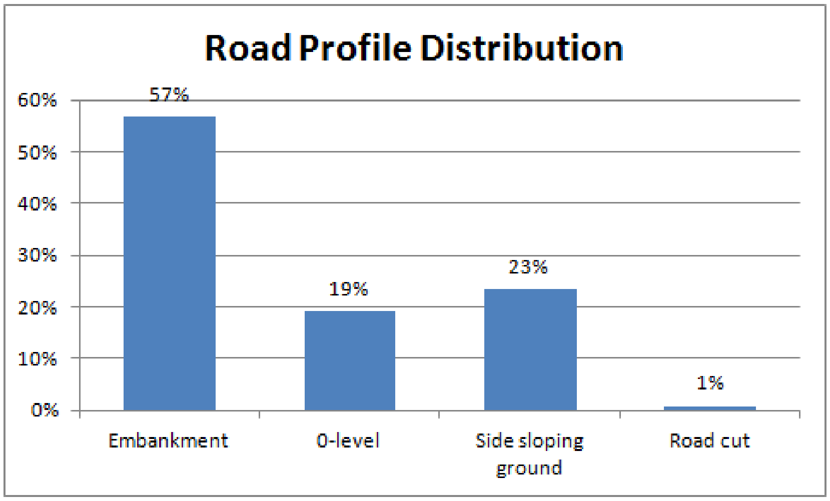

Figure 55: Distribution of road profiles in the Icelandic demonstration project.

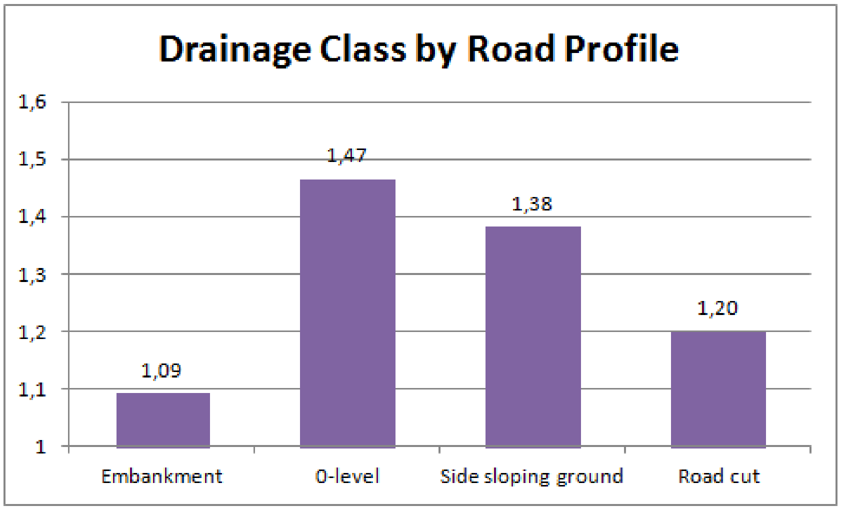

Figure 56: The average drainage class in different road profiles in Iceland.

6.1.1. Summary of Drainage and Verge Classes

The drainage condition of the surveyed roads was divided into three different classes: Class 1 (Good condition), Class 2 (Adequate condition) and Class 3 (Poor condition). The vast majority by far of the surveyed chainage was classified as drainage Class 1 which covered 79% of the chainage (Figure 57). This leads to a conclusion that the drainage condition in Iceland was on average at an excellent level compared to the other ROADEX drainage demonstration projects.

The verges were classified into two classes: Class 1 (No verges), Class 2 (Verges exist). For the most part the verges on the Icelandic roads surveyed were not hindering the workings of the drainage; only 13% of the chainage had a verge present (Figure 58).

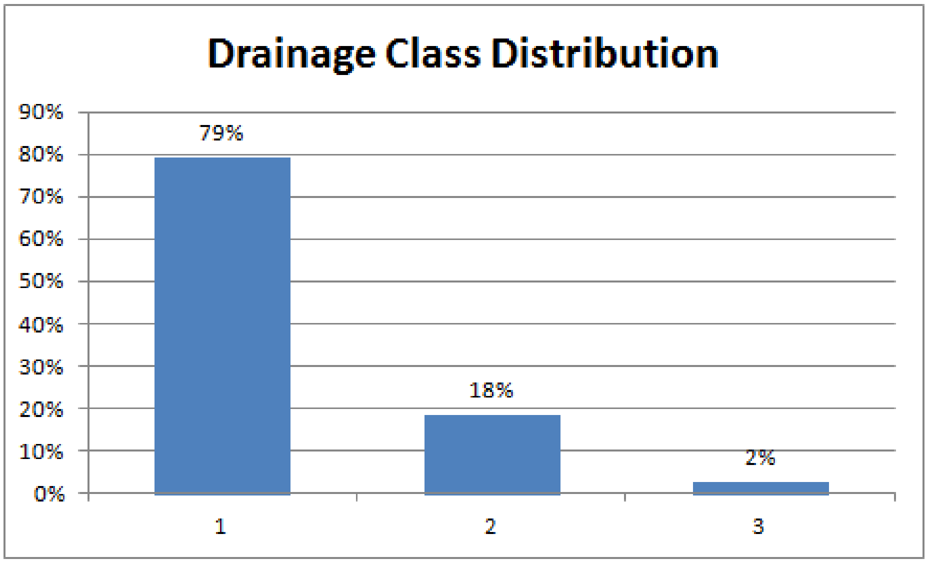

Figure 57: Distribution of the drainage classes in the Icelandic demonstration project.

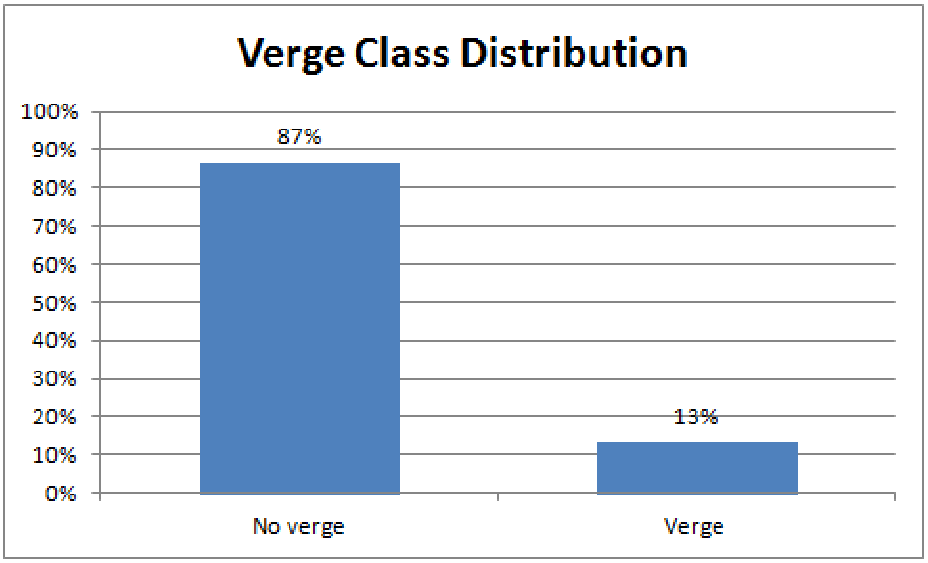

Figure 58: Distribution of the verge classes in the Icelandic demonstration project.

6.2. DRAINAGE AND ROAD PERFORMANCE

6.2.1. Effect of Drainage on Roughness

The only roughness data available for the Icelandic roads was averaged to 20 metres. Most of the data was from the year 2008 and the rest from 2006 and 2007, which meant as a whole that the data was relatively old. In previous ROADEX demonstration projects it has been found that data averaged to 10 metres usually gave more accurate results. Only one of the five surveyed sections in road 36 had IRI data available.

In general, road profilometer data in the other demonstration projects correlated well with the drainage deficiencies identified. However in the surveyed Icelandic roads the analysis showed that IRI data did not correlate with drainage conditions, and actually IRI values were lower in drainage Class 3 than in Class 1 (Figures 59-60).

The most likely reasons for this evenness in the roughness data were the amount of dry terrain, and the exceptional road profile distribution. The dry terrain also helped with the average drainage condition which was at a very good level. As already mentioned, the prevailing road profile in the surveyed road sections was embankment, approximately 57%. On embankments drainage deficiencies usually have less impact on road condition.

The Icelandic practice of placing the ditch further from the road edge may also have some effect on the result by keeping potential drainage problems further away from the road.

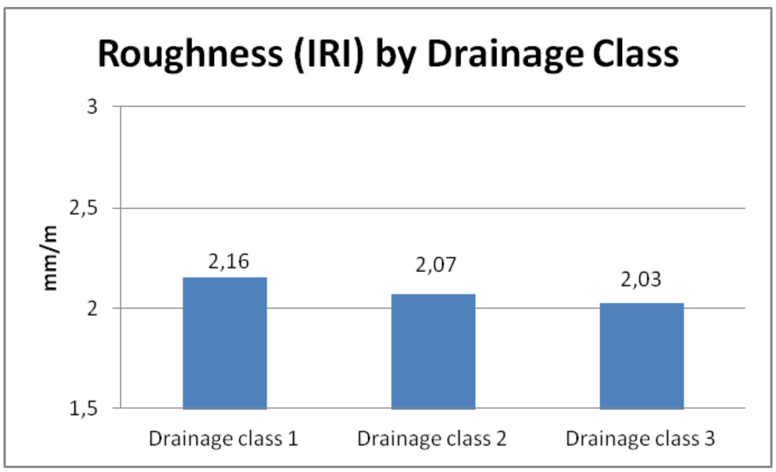

Figure 59: IRI values by drainage classes in Iceland. IRI values are 20m averages.

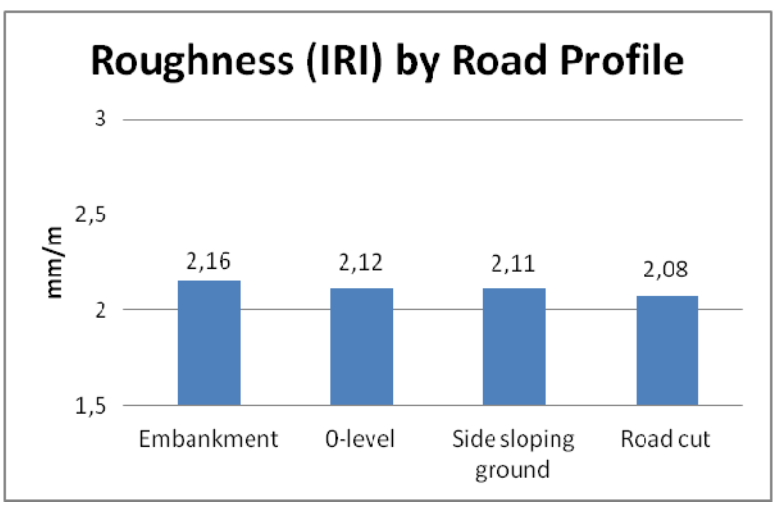

Figure 60: IRI values by road profiles in Iceland. IRI values are 20m averages.

6.2.2. Effect of Verges on Roughness

The presence of roadside verges normally has an effect on rutting and roughness on the adjacent road as they prevent water from freely flowing off the road surface, and this can cause problems over time. The absence of rutting data from Iceland unfortunately prevented an analysis of rutting versus verges and only a roughness analysis could be made.

In the roads surveyed in Iceland there was not a discernible change in IRI values between sections with or without verges (Figure 61). Part of the explanation could be the data itself which was, as already mentioned, relatively old.

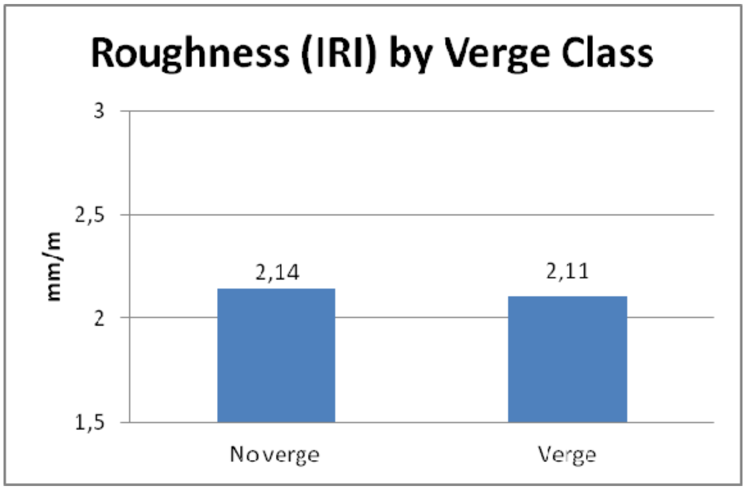

Figure 61: IRI values by verge class in Iceland. IRI values are 20m averages.

6.3. LASER SCANNER

In the majority of the road sections surveyed the road drainage ditches had been constructed far from the road, and too far to be usefully scanned by the laser scanner. Section 11 of road 36 was selected to test the ditch depth analysis method as it had a significant part of its ditches closer to the road edge. The laser scanner survey of section 11 found that the vast majority of the ditches had a good depth (Table 2). According to Icelandic national recommendations the ditch depth should be 20-30cm lower than the bottom of road structure.

Table 2: Statistical ditch depths on section 11 of road 36.

	>50cm	>80cm
Left Ditch	98.8%	93.9%
Right Ditch	100.0%	99.0%

Two example sections from section 11 on road 36 are shown in Figures 62 and 63. A GPR survey was not carried out as part of the Icelandic demonstration project so the bottom of the road structure could not be determined. The coloured bars on top of the figures represent the assumed bottom of the structure which is divided into two layers. The uppermost red bar in both figures represents a 50cm thick road structure and the green bar represents an 80cm thick structure. The red line represents the bottom of the left ditch calculated from the road centreline elevation and the blue line represents the bottom of the right ditch. On Figure 62 the left (red) ditch is shallow from 4820m to 4850, and the right (blue) ditch is deeper than the scale (3.0m) from 4810m onwards.

Figure 62: Ditch depth shown as a continuous ditch depth field and as a cross section view at chainage 4785m. The red arrow indicates the left ditch and the blue arrow indicates the right ditch. On the left from 4820m to 4850m there was a short section where the ditch was shallow.

The roadside ditch on the left was shallow for a few short sections from 4700m to 5600m. Where the ditch depth is not shown on the map it was either too far from the road or there was not a need for a ditch at all.

Figure 64: Ditch depth map of section 11 on road 36.

7. CONCLUSIONS

The overall drainage condition of the surveyed roads in Iceland was good or excellent. No less than 79% of the surveyed chainage was in drainage Class 1. The dominant road profile was embankment; in total 57% of the chainage was in that road profile. This was very different to other ROADEX drainage demonstration projects surveyed previously.

As already mentioned the only available roughness data for the surveyed road sections was averaged to 20 metres. The analysis results showed that the drainage deficiencies did not correlate with the available roughness data. Part of the explanation for this could be that most of the roughness data was quite old.

In Nordic countries verges are considered as harmful features that should be removed. Previous ROADEX drainage demonstration projects have shown that the correlation between roughness and the presence of verges was usually strong. In Iceland the statistical analysis showed that the roughness data did not correlate with the presence of verges at all. The statistical roughness was at the same level if there was verge at present or not.

In some locations the outlet ditches were not working efficiently enough. Water and vegetation was standing in some of the outlet ditches. Mostly this was due to the flat terrain and for that reason any improvement could be challenging to effect.

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. In the project in Iceland the laser scanner provided some interesting results regarding changes to the road crown section which could not be detected by human eye. The data from the laser scanner also showed sections with shoulder deformation problems. Only one road section was tested for ditch depth calculation using laser scanner data as generally the drainage ditches had been provided far from the road. Where it could be used however the depth calculation test was successful, and the results were in line with other demonstration projects where the method had been tested before.

The drainage analysis of the surveyed road sections in Iceland identified those sections that had drainage deficiencies even though they had minor effects on the adjacent road condition. It is recommended that those sections, and the poor outlet ditches identified, should be improved. In this way, possible problems in the future can be avoided.

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
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- 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.