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ROAD WIDENING

Field survey report

ABSTRACT

As a part of the ROADEX IV road widening project a range of widened roads were surveyed in Finland, Sweden, Norway and Scotland using multiple technologies such as ground penetrating radar, video, laser scanners, thermal analysis and falling weight deflectometer. Some of the sites had already been surveyed in the first ROADEX project 1998 - 2001. All of the sections studied provided a good overview of the different types of problems that can occur due to the design and construction of a road widening.

The so called "light widening" structure was performing well on the surveyed section of the Hw9 in Finland where the old structure was strong enough and the subgrade was not frost susceptible. The same structure however failed in Ohtanajärvi in Sweden where the road was original widened and slightly strengthened from a weak old gravel road suffering from frost action and Mode 2 rutting problems.

The results from road 75 in Finland showed that the widening carried out 15 year ago was executed well and the defects surveyed in the widened areas were most likely triggered by poor drainage maintenance. The road was showing pavement distress but the defects were related to the fatigue of the old structures due to heavy traffic.

The results from steel reinforcement structures used in the ROADEX tests in Lapträsk in Sweden and in Killimster Moss in Scotland showed that the reinforcement should be installed deep enough, particularly where the subgrade is peat as it was in Killimster Moss where the road was performing well in sections where the installation was at depth of 200-250 mm. The Killimster Moss tests also showed that the risk of failures was much higher if the steel grid was installed directly on the top of concrete slab.

The Salmi test section in Sweden presented an example of reflection cracking caused by a sandwich structure and the results from the Karrbäck road section showed some settlement and severe rutting taking place on the widened side. The main problem at Karrbäck was that the whole road was settling into the extremely soft silty subgrade and the drainage was not working at all.

The results from the Engerud road in Norway showed that the glassfibre strengthening had not been able to prevent the reflection cracking taking place. From this it can be concluded that glassfibre is not an adequate strengthening method, if there are vertical shear forces due to frost action taking place in the widening joint. The geogrid test data from Sibster in Scotland gave similar results but the reason at Sibster was differential settlements, and high and varying deflection behaviour on a road resting on peat.

The test results in the old ROADEX test sections resting on peat (Kjosenmyra in Norway and Sibster in Scotland) showed major improvement in the road condition over the last ten years. This can be explained by the fact that the greatest part of peat consolidation beneath the widened area had taken place and the peat stiffness was similar in the road centre and on the widened area.

The Rogart test section in Scotland was still performing well. It was last surveyed 10 years ago. The only small point noted was a minor settlement in the widened area indicating inadequate compaction during the widening construction.

PREFACE

This report is a part output of ROADEX IV project task D2 “Widening of Roads”. The project aims to provide information on the reasons why road widenings fail, the critical parameters that the road engineer needs to know when designing a road widening, and the information on how to deal with a widened road that is showing problems. The cost effective widening of roads is a major issue facing the ROADEX Partners and new design guidelines specifically tailored to the harsh conditions of the Northern Periphery are required to meet the demands of modern traffic.

The ROADEX road widening research task consisted of three phases. The first part was a literature review on current practices and guidelines for road widening in the ROADEX countries. The report entitled “Road Widening: literature review and questionnaire responses” was written by Samuli Tikkanen from Tampere University of Technology assisted by Timo Saarenketo from Roadscanners, Nuutti Vuorimies and Pauli Kolisoja from Tampere University of Technology and Ron Munro from Munroconsult Ltd. Also Haraldur Sigursteinsson of the Icelandic Road Administration, Per Otto Aursand of the Norwegian Public Roads Administration and Johan Ullberg from Swedish Road Administration provided information on existing road widening guidelines for the report.

This report describes the second part of the project that dealt with field surveys on selected widening test sites across the ROADEX countries. A range of widened roads were surveyed using multiple technologies such as ground penetrating radar, video, laser scanners, thermal analysis and falling weight deflectometer. Some of the sites of the ROADEX pilot project (1998 – 2001) were visited as part of this work. The report was written by Petri Varin and Timo Saarenketo and the language was checked by Ron Munro.

The third part, and the final goal of the project, was to provide a ROADEX guideline for road widening for low volume roads. This report combines many good practices from different Partner countries into one package. The main purpose of the report is to act as a practical ‘pocket book’ and check list, to be used alongside national guidelines, on what to keep in mind when considering road widening projects and when repairing problematic widened roads. The report was also written by Petri Varin and Timo Saarenketo.

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1. INTRODUCTION

A road widening project is usually commissioned when the road width is not adequate for the traffic, or when extra lanes are needed. Road widening can improve traffic safety and capacity.

There are many special issues in road widening. If widening is made poorly, several problems can occur, and many are common to all ROADEX countries. Typical problems in road widening are construction joint cracking between the old and new parts of the road, non-uniform settlements between the old and new part of the embankment and stability problems. In cold areas frost action causes significant additional problems. Harmful effects however can be avoided by good survey and design. Damages can be avoided or repaired by using techniques such as geo-reinforcement, steel nets, stabilization and soil replacement, and by improving drainage. These methods usually increase construction costs, but they can decrease life cycle cost. Choosing the correct widening or repair method and structure is therefore very important for avoiding additional long term costs.

This report highlights the findings and the results of the field surveys performed on selected widening test sites in the various ROADEX countries. The main goal of the surveys was to provide more information on road widening, to be used as a basis for writing the ROADEX road widening guidelines. The new guidelines are a combination of the current good road widening practices in different partner countries and the results of the ROADEX IV field surveys. Surveys were made in Finland, Sweden, Norway and Scotland. A range of widened roads were surveyed using multiple technologies such as ground penetrating radar, video, laser scanners, thermal analysis and falling weight deflectometer. Some of the sites of the first pilot ROADEX project (1998 – 2001) were visited again as a part of this work.

Many road widenings fail without engineers knowing the reasons for the failures. The goal in this report will be to improve road widening diagnostic methods in order to find objective information on the reasons for the failures. For this new technologies and their integrated analysis methods need to be tested.

There are a number of differences between the nationally agreed guidelines on road widening across the ROADEX partner countries. Some of the countries have national guidelines and some have not. The guidance given for road widening instructions is generally similar but there are also some differences reflecting the fact that widening design and construction can be carried out in many ways. The previous report "Road Widening: literature review and questionnaire responses" discussed the national guidelines in the ROADEX countries and compared the differences, and the similarities, between them. Road widening tests and research reports were also reviewed. One purpose of the report was also to study road widening practice in the ROADEX countries. A road widening related questionnaire was created and sent out to experts in the ROADEX countries in order to collect their experience and knowledge of road widening. Responses to the questionnaire were examined and discussed in detail in the report. A summary of the results of the literature review and the questionnaire responses is given as an appendix to this report.

2. SURVEY SITES

The ROADEX road widening field surveys were made in Finland, Sweden, Norway and Scotland. Some of the sites were same as the first ROADEX project in 1998 - 2001. The locations of the survey sites are shown on the maps in Figures 2_1 and 2_2.

The first Finnish site was a 21 km long section of highway 9 located in Suonenjoki, Central Finland. The widening structure on Hw 9 was constructed in summer 2010. The second Finnish site was a 35 km section of road 75 between Nurmes and Kuhmo in Eastern Finland. It is an older road that was rehabilitated and previously widened in 1995.

The Swedish sites were located in Northern Sweden, near the Finnish border. The Ohtanajärvi site was a 400 m long section of road 857. The Salmi site was a 500 m long section of road 392. The Karrbäck site was a 300 m long section of road 767 and the Lappträsk site was a 300 m long section of road 398. These sites were previously surveyed in the first ROADEX project.

The Norwegian sites were located in Northern Norway, near Troms. The Engerud site was a 200 m long section of road 855. The Kjosemyra site was a 300 m long section of road 858 and the Tennes site was a 500 m long section of road 859. These sites were also previously surveyed in the first ROADEX project in 2001.

The Scottish survey sites were located in Highland region in Northern Scotland. The Killimster Moss site was a section of road B876. The Sibster site was a section of road B874 and the Rogart site was a section of road A839. All of these sites were previously surveyed in earlier ROADEX projects.



Figure 2_1. ROADEX road widening survey sites in Finland, Sweden and Norway



Figure 2_2. ROADEX road widening survey sites in Scotland

There are many special issues in road widening and various reasons for failures. A range of widened roads were surveyed representing different kinds of problems and circumstances. Some of the sites were of roads built on a peat subgrade, some were widened and upgraded from an old gravel road, some were showing reflection cracking, etc. Table 2.1 gives a summary of all the survey sites and their primary problems and/or reasons why they were selected.

Table 2.1. ROADEX road widening survey sites and their primary problems and/or reasons why they were selected as test sites.

SITE	COUNTRY	PROBLEMS / REASONS FOR SURVEYS
Suonenjoki	Finland	new structure, "light widening", widening to both sides
Nurmes	Finland	15 year old widening, severe pavement damages
Ohtanajärvi	Sweden	upgrading and light widening from old gravel road, "unwanted widening"
Salmi	Sweden	widening of stronger construction, sandwich structure, reflection cracking
Karrbäck	Sweden	widening on very soft subgrade, drainage problems
Lapträsk	Sweden	steel reinforcement
Engerud	Norway	reflection cracking due to widening
Kjosemyra	Norway	road constructed and widened on peat subgrade
Tennes	Norway	widened and upgraded from old gravel road
Killimster Moss	Scotland	widening of concrete road, the use of steel reinforcement
Sibster	Scotland	road widened on peat subgrade, geogrid reinforcement
Rogart	Scotland	relatively well behaved widening, minor edge damage bends with grass verges

3. SURVEY TECHNIQUES

Carefully performed surveys and measurements are essential before starting the design of a road widening. It is important to find out the conditions on the site such as the thickness of the old road structural layers, the material properties of the subgrade and layers in the old embankment, the road shape and its surroundings, any problem areas and damages on the existing road, etc. The type and range of survey techniques to be used will depend on each individual case, but typically at least video recording, laser scanner measurement and GPR measurement should be made. A short description of the techniques used in the ROADDEX road widening field surveys is given in the following chapters. All of the techniques listed are discussed and explained elsewhere in more detail, e.g. in the E-Learning package on ROADDEX website (www.roadex.org).

3.1. DIGITAL VIDEOS

A Road Doctor CamLink system was used for the video data collection, (Figure 3.1_1). This system is designed to collect videos, audio commentary and a drainage or pavement distress inventory on the road, together with GPS coordinates. Modern digital photo and video techniques provide very useful tools for documenting a road, its surroundings and pavement damages. Visual recording is vital to make the correct diagnosis of any problems on the existing road. Video recording gives a continuous record of the road. It can detect road surface condition, pavement distress, road markings, traffic signs etc. It can also be a very useful aid in surveying the topography of the road and its surroundings. Video recording is a useful tool for comparing the road condition before and after widening.

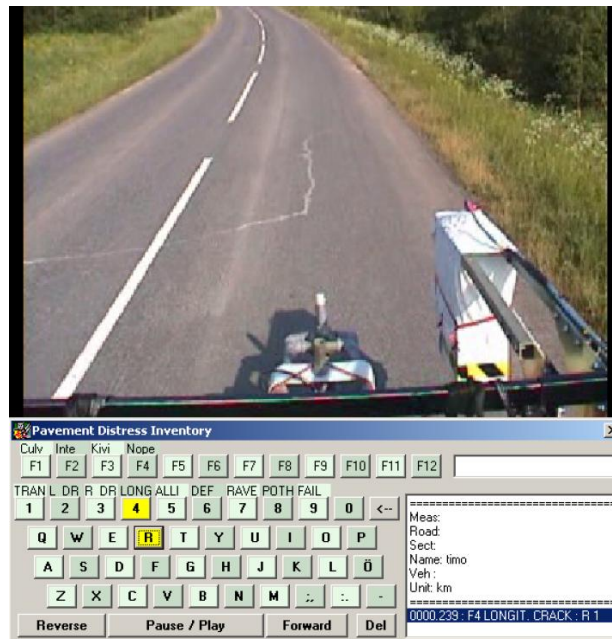


Figure 3.1_1. Digital video recording and pavement distress analysis

3.2. LASER SCANNING

Laser scanning (Figure 3.2_1) is a technique where the measurement of distance is derived 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 to a range of directions from a moving vehicle with a known position, it is possible to make a surface image, or "point cloud", of a road and its surroundings. The point cloud can have millions of points, with every point having x, y & z coordinates and additional reflection or emission characteristics.



Figure 3.2_1. Everyman's RDLS laser scanner survey vehicle used in ROADDEX surveys

The laser scanner technique was used in many sites in the ROADDEX road widening research project to obtain continuous height information and cross section profile of the road. From this information useful data can be obtained, e.g. the angle of side slopes which can help in evaluating the effects on the slopes due to widening. Other useful parameters that can be obtained are the road width and the ditch depth. Laser scanning is a very efficient tool for comparing the road profile before and after widening. Figure 3.2_2 gives an example from the Finnish ROADDEX test site on Hw 9 showing height and cross section information from a laser scanner survey before and after a road widening. A combination of laser scanner data together with other road survey data can provide an excellent basis for analysing the reasons for failures on an existing road.

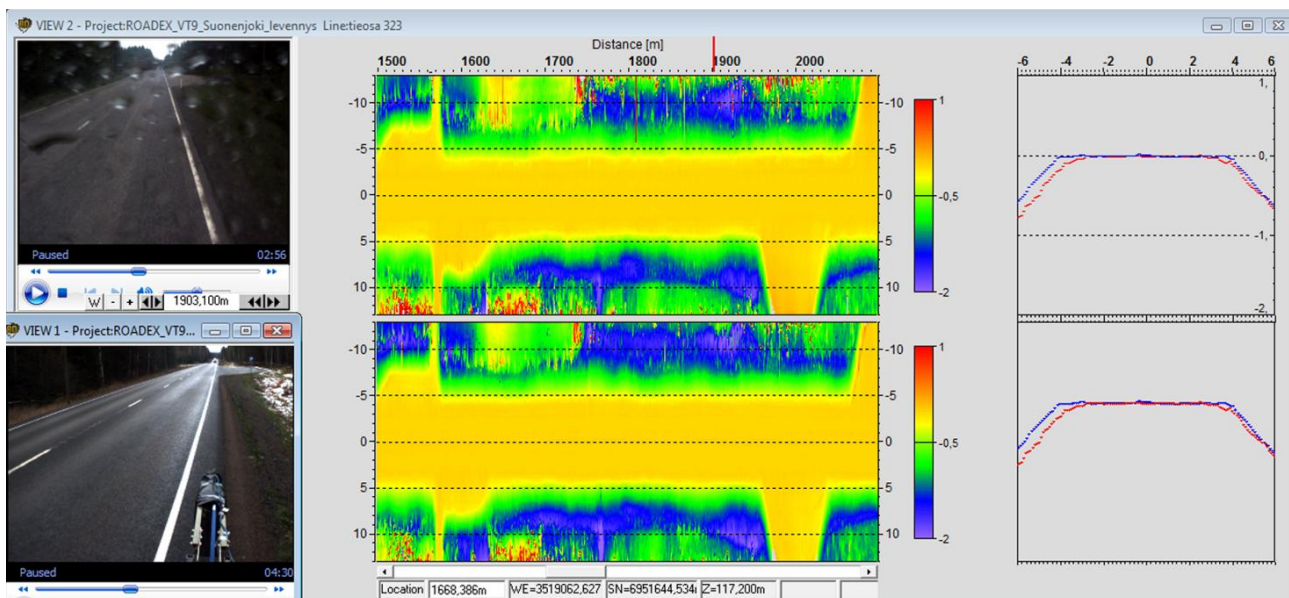


Figure 3.2_2. An example from Hw 9, Finland showing height and cross section information from a laser scanner survey before (above and red) and after (below and blue) road widening

3.3. GPR SURVEYS

Ground Penetrating Radar (GPR) data collection and analysis is one of the most important survey techniques. It provides continuous information on the thicknesses and the quality of the road

structural layers. GPR measurements should be done in 3D for road widening works using several parallel longitudinal profiles, and GPR cross sections are also recommended (Figure 3.3_1).



Figure 3.3_1. LEFT: Survey vehicle used in ROADDEX road widening surveys. GPR antennas are mounted in front of the van, video and GPS equipment are on the roof and laser scanner is on the back. RIGHT: GPR cross section measurement equipment.

GPR cross sections are especially important in road widening cases for the evaluation of the performance of the widening and the reasons for any damages. Cross sections can, for example, provide information on the differences in layer thicknesses and/or material properties, old structures below or inside the road structure, settlement and rutting problems. Rutting mode can also be determined from GPR cross sections. The correct identification of the reasons for rutting on the existing road can help in selecting the most appropriate widening or repair method.

3.4. THERMAL CAMERA MEASUREMENTS

Thermal camera measurements can provide a continuous thermal video recording of the whole road length. The temperature distribution over the road's cross section can be obtained from the data and analyzed to locate any temperature differences between the widening and the old road structure. A non-uniform temperature distribution may be an indication of possible frost or moisture problems.

3.5. FALLING WEIGHT DEFLECTOMETER SURVEYS

The Falling Weight Deflectometer (FWD) is an automated stationary impulse load method used to measure deflections in the road surface, which can then be used in calculating the bearing capacity of the road (Figure 3.5_1). From FWD measurements the E-modulus value of each structural layer and the subgrade can be calculated, and these moduli can then be used for calculating the bearing capacity of the existing road and for the widening design. The FWD can be used for many purposes in addition to bearing capacity measurement, for example the investigation of reinforcement requirements, identifying weak spots on the road, establishing priorities for road strengthening, as well as monitoring the strength of layers during construction.



Figure 3.5_1. Falling Weight Deflectometer (FWD)

3.6. DATA ANALYSIS TECHNIQUES AND SOFTWARE USED

All of the data collected in the surveys was processed and analyzed using Road Doctor Pro software. This software enables GPR, FWD, laser scanner and other data to be combined together with videos and maps. The Thermal Diagnostics module of the Road Doctor Pro software was used to process the thermal camera data. “Elmod 6” software can be used to back calculate the layer moduli values on the basis of the FWD data and the layer thicknesses. This was used in an integrated module with Road Doctor Pro software. An integrated data analysis utilizing comparisons and correlations between different factors affecting the road behavior is easier to make when all the data is linked together.

4. SURVEY RESULTS

This chapter highlights the key findings and results of the field surveys performed on the selected widening test sites across the ROADEx partner countries. A range of widened roads were surveyed to give a range of examples of different kinds of widening techniques and problems. Multiple survey technologies, as presented in the previous chapter, were used.

4.1. FIELD SURVEYS IN FINLAND

4.1.1. Suonenjoki, highway 9

The Suonenjoki Highway 9 is an example of a road that has been widened on both sides. A detailed drawing of the Hw 9 widening structure is shown in Figure 4.1_1. This structure could be termed a “light widening” as the widening was restricted to the road shoulders, and because the shoulders were excavated only to a depth of 350 mm. The existing pavement was cut just outside the driving lane edge. The new structural layers consisted of 250 mm of unbound aggregate, 60 mm of bitumen bound base course and finally 40 mm of stone mastic asphalt for a wearing course. After the widening the traffic still used the former lanes with the widening solely contained in the shoulder and safety area (Figure 4.1_2). When widening on both sides of the road, construction joint cracking and non-uniform settlement normally develops in the shoulders, and not in the loaded part of the road.

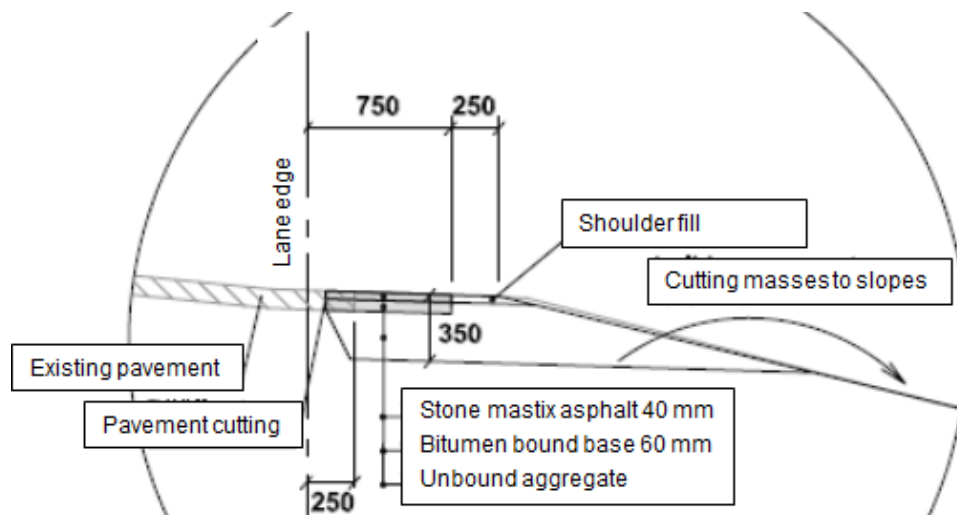


Figure 4.1_1. Detail drawing of the Hw 9 widening structure



Figure 4.1_2. Widening on both sides of Hw 9 in Suonenjoki, Finland. After widening the traffic load is still on the old lanes and the widening is restricted to the shoulder and safety area only. See also the drainage improvement.

Digital video recordings and laser scanner measurements were carried out four times on Hw 9. The first time was in May 2010 before construction of the widening structures. The second measurement was done in October 2010 after the construction was finished. The third time was in May 2011 in order to see the changes of the cross section profile after the first winter and to find any uneven frost heave locations. GPR cross sections were measured in summer 2011. Finally follow-up measurements with video and laser scanner were made in May 2012.

Figure 4.1_3 shows an example of a GPR cross section measured from the road. The bottom of the excavation before widening is on the same level as the bottom of the unbound base course on the old road. This is a good practice to achieve uniform behaviour. The Figure also shows that the overall thickness of the bound layers is somewhat thicker on the old driving lanes than on the new widened shoulders, but the traffic loading is also much less on the shoulders.

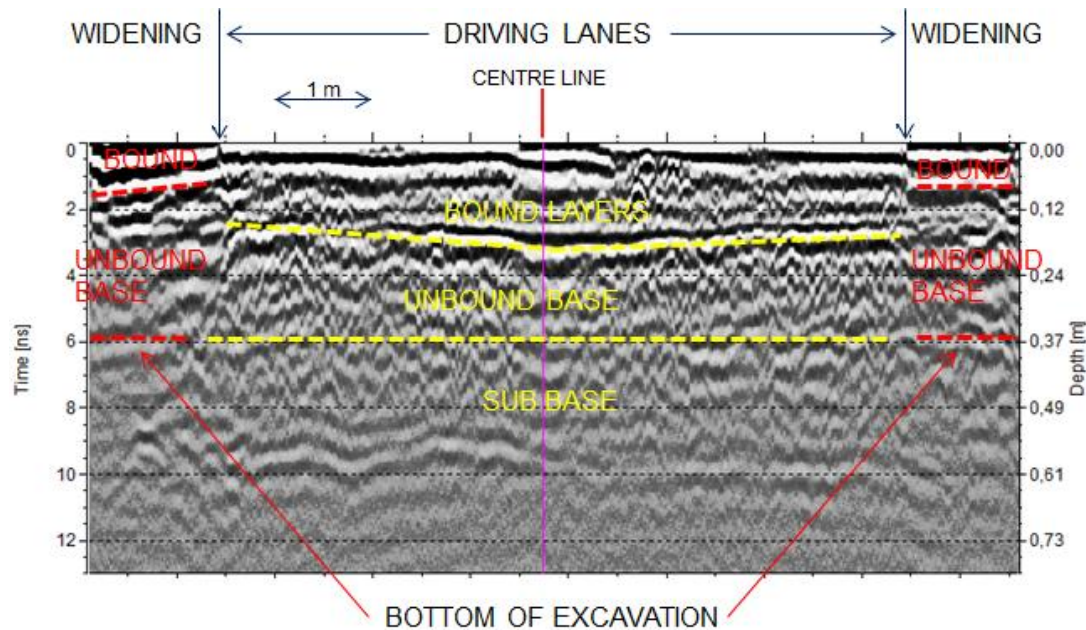


Figure 4.1_3. GPR (1.5 GHz) cross section of the widened structure on Hw 9

The monitoring results after the first frost season following widening showed no distress, such as cracks between the old road and the widening, or differential frost heave problems. The widening and the whole road were generally in a very good condition. Examples of the general condition in spring 2011 are presented in Figure 4.1_4. There were only some transverse cracks, longitudinal frost cracks in the middle of the road and opened pavement joints between driving lanes, but none of these were related to the widening. Examples of the damages in spring 2011 are presented in Figure 4.1_5.



Figure 4.1_4. Examples of the Hw 9 general condition in spring 2011, after first frost season



Figure 4.1_5. Examples of the Hw 9 damages in spring 2011

On the basis of the laser scanner measurements it can be concluded that the road section has maintained its shape very well, i.e. there are no major changes in the cross section profile when compared to the autumn 2010 measurements just after widening. Figure 4.1_6 gives two examples of laser scanner cross section profiles showing the situation in May 2010 (red colour, before widening), in October 2010 (black colour, after widening), and in May 2011 (blue colour, after the first frost season). From the figure it can be observed that the black and the blue cross section are almost exactly the same. The results also show that the repeatability of laser scanner measurements is good.

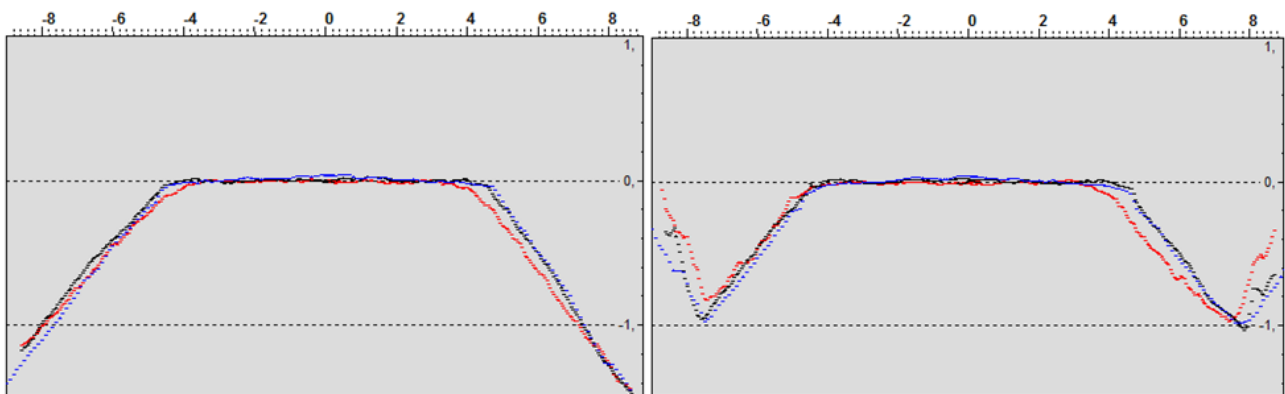


Figure 4.1_6. Examples of laser scanner cross sections in May 2010 (red, before widening), in October 2010 (black, after widening), and in May 2011 (blue, after the first frost season)

The results of the follow-up measurements with video and laser scanner in spring 2012 showed unchanged circumstances when compared to spring 2011 measurements. An example photograph from the same location in 2011 and 2012, representing the general condition of the road, is shown in Figure 4.1_7.



Figure 4.1_7. Comparison of the Hw 9 general condition in spring 2011 and spring 2012

In 2012, after two frost seasons, the widening structure was still in very good condition, which can be confirmed in the results of the pavement distress analysis summarised in Table 4.1.1. This was assembled in spring 2012 using the follow-up video recording. Other damages (mainly longitudinal frost cracks and opened pavement joints between driving lanes) covered 9.15 % of the road length surveyed, but none were related to the widening..

Table 4.1.1. The results of the Hw 9 pavement distress analysis in spring 2012, after two frost seasons following construction

Road section	Other damages		Damages related to widening	
	[m]	[%]	[m]	[%]
321 (length 5039 m)	607	12.05	0	0
322 (length 4127 m)	412	9.98	0	0
323 (length 4599 m)	459	9.98	0	0
324 (length 4136 m)	279	6.75	0	0
325 (length 3000 m)	156	5.20	0	0
total length 20901 m	1913	9.15	0	0

Figure 4.1_8 gives two examples of the laser scanner cross section profiles showing the comparison between the spring 2011 measurements and the spring 2012 follow-up measurements. The figures show that no changes in road's cross section shape have taken place.

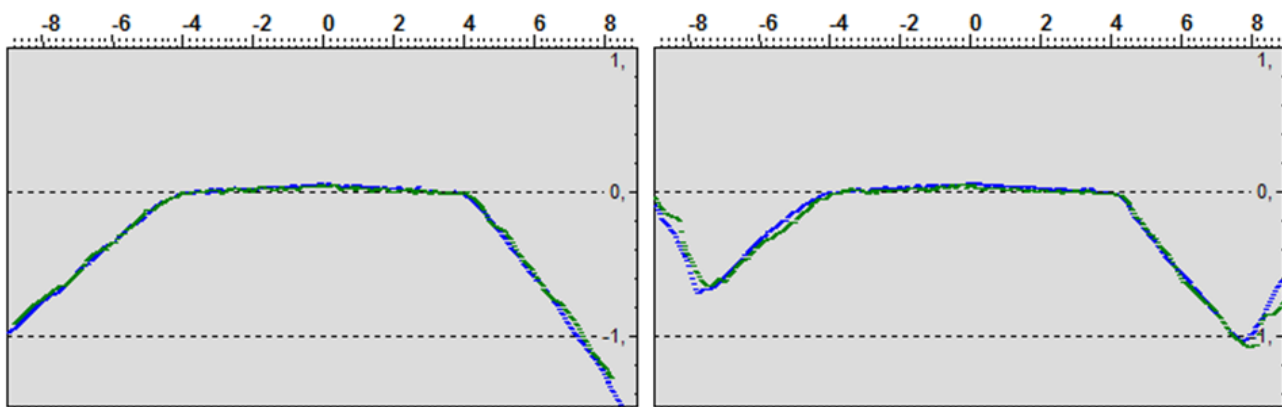


Figure 4.1_8. Examples of laser scanner cross sections in May 2011 (blue, after the first frost season) and in May 2012 (green, after two frost seasons)

A thermal camera survey was also carried out on the Hw 9 widening section. On the basis of the measurements, the general temperature distribution of the road was seen to be very uniform. Even

though there was some difference in pavement thickness, no significant temperature difference between the widened road shoulder and the old road structure could be noticed. Figure 4.1_9 presents an example showing normal digital video, thermal video and a “temperature map” calculated from the thermal camera data. The uniform temperature distribution can be observed from the thermal video and the temperature map. The repaired frost crack in the middle of the road can be seen cooler than its surroundings.

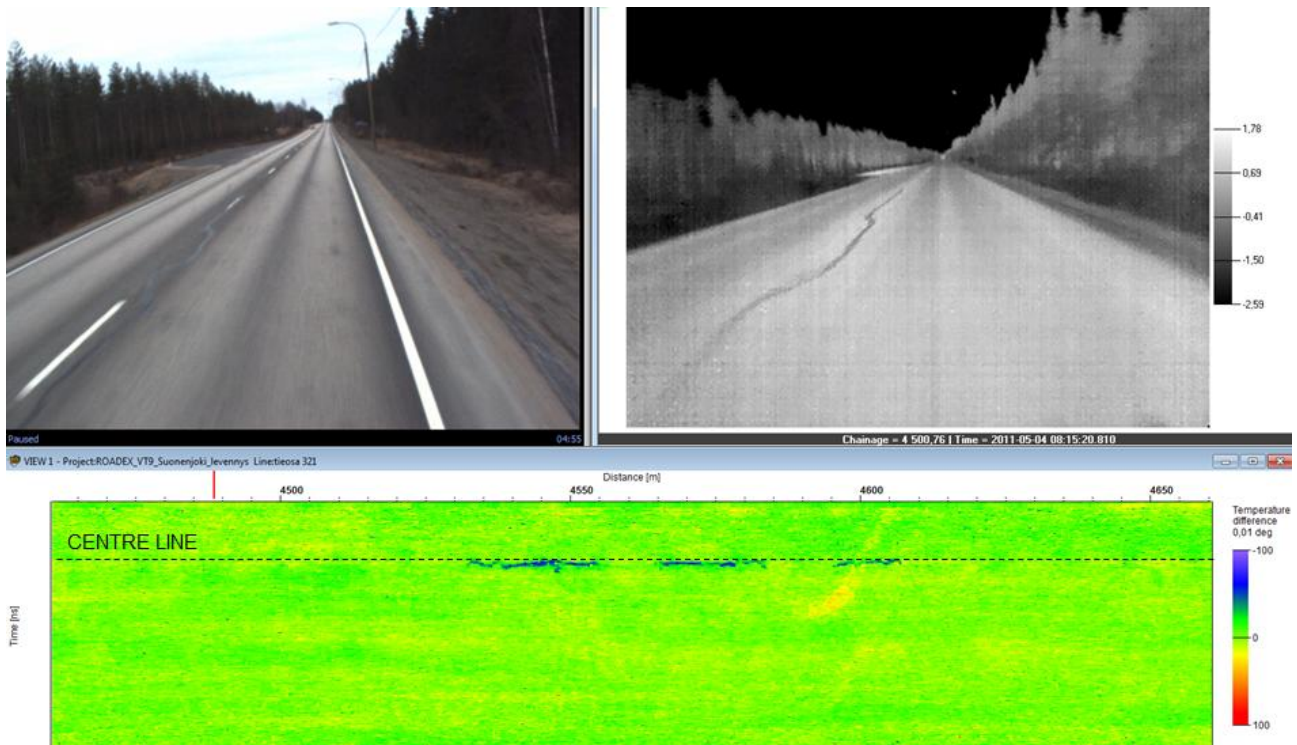


Figure 4.1_9. An example of the results of thermal analysis on Hw 9. The longitudinal crack in the middle could be associated with the end of the rest area, indicating possible drainage problems.

As a summary it can be stated that the “light widening” structure on Hw 9 has been working very well for the first two years after construction. The road has maintained its cross section profile shape, there is no pavement damages related to the widening structure, and no temperature anomalies either. Indications of rapid development of damages were not observed during the follow-up period.

4.1.2. Nurmes, Road 75

The other Finnish test road section was an older road that had previously been rehabilitated and widened in 1995. This road had problems with a high amount of pavement distress and it was selected to be ROADDEX road widening test site due to the interest to know if the problems were due to the road widening. A visual survey done on the site did not however show many damages on the road that could be clearly related to the road widening. On the other hand the road had much other damage, the vast majority of which were alligator cracking on the wheel paths indicating pavement fatigue as a result of thin structures, heavy loading and poor drainage. There were also many patched sections and some shoulder deformation. Examples of the most typical damage types are shown in Figure 4.1_10. Table 4.1.2 summarises the statistics from the pavement distress analysis and shows that only a minor percentage of the damages could be considered to be related to the road widening. The Table shows that only 4-6 % of the distress could be related to road widening while general pavement distress could be seen on 55 % of the Direction 1 and 70 % of Direction 2.



Figure 4.1_10. The majority of the damage type on Road 75 was alligator cracking on the wheel paths due to pavement fatigue. There were also many patched sections.

Table 4.1.2. Results of Road 75 pavement distress analysis

Road section	All damages		Damages possibly related to widening	
	[m]	[%]	[m]	[%]
24 / direction 1 (length 7589 m)	5619	74.04	732	9.65
24 / direction 2 (length 7589 m)	6144	80.96	827	10.9
25 / direction 1 (length 4344 m)	3620	83.33	397	9.14
25 / direction 2 (length 4344 m)	3942	90.75	121	2.79
26 / direction 1 (length 6395 m)	3743	58.53	129	2.02
26 / direction 2 (length 6395 m)	5229	81.77	425	6.65
27 / direction 1 (length 4201 m)	2774	66.03	130	3.09
27 / direction 2 (length 4201 m)	3420	81.41	298	7.09
28 / direction 1 (length 9002 m)	2297	25.52	71	0.79
28 / direction 2 (length 9002 m)	3788	42.08	347	3.85
29 / direction 1 (length 3421 m)	1302	38.06	86	2.51
29 / direction 2 (length 3421 m)	1956	57.18	157	4.59
Direction 1 total (length 34952 m)	19355	55.38	1545	4.42
Direction 2 total (length 34952 m)	24479	70.04	2175	6.22

Figure 4.1_11 shows an example section from Road 75 with an analysis of the reasons for the typical alligator cracking damages. The total thickness of the road structure was in many places very thin 0.4 – 0.6 m), which can be seen in the GPR data profile in the top window. The road drainage is also not working properly. In this example the road is located on side sloping ground and the upper ditch is too shallow. The red lines show the locations of the laser scanner cross section profiles.

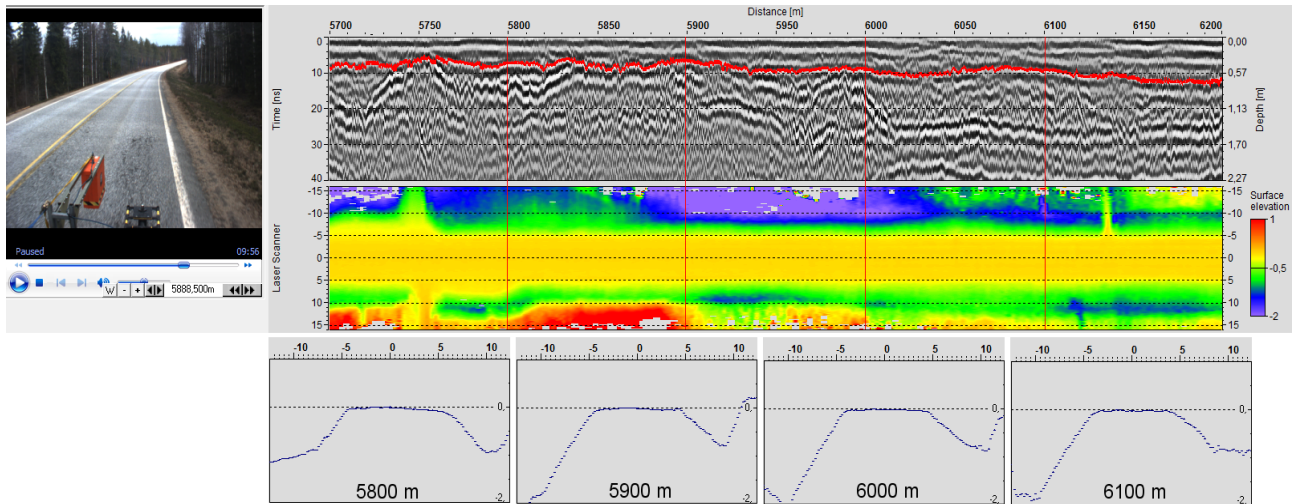


Figure 4.1_11. An example indicating the reasons for the typical alligator cracking damage on Road 75. The total thickness of the road structure is very thin. Drainage is not working properly due to the upper ditch on side sloping ground being too shallow. The top field gives the 400 MHz GPR data, the middle field is the laser scanner height map, and the lowest field presents laser scanner cross sections. The red lines show the locations of the cross section profiles. The video still photograph on the top left is from chainage 5890 m.

Damages due to road widening were seen along all the road sections. Examples are shown in Figure 4.1_12.



Figure 4.1_12. Examples of widening related damages on Road 75

Typical reasons for road widenings to fail are the differences between the old part and the new widened part of the road in structural thickness, material properties and/or degree of compaction. These differences may cause various problems such as differential frost heave, uneven settlements, reflection cracking or different load bearing capacity between the old and the new part of the structure. Figure 4.1.13 shows an example of such a case from Road 75. The red arrow points to the location of the crack on the GPR cross section. From the cross section it can be observed that there is discontinuity and some difference in thickness between the old and the new part of the structure in base course thickness and also in total structure thickness.

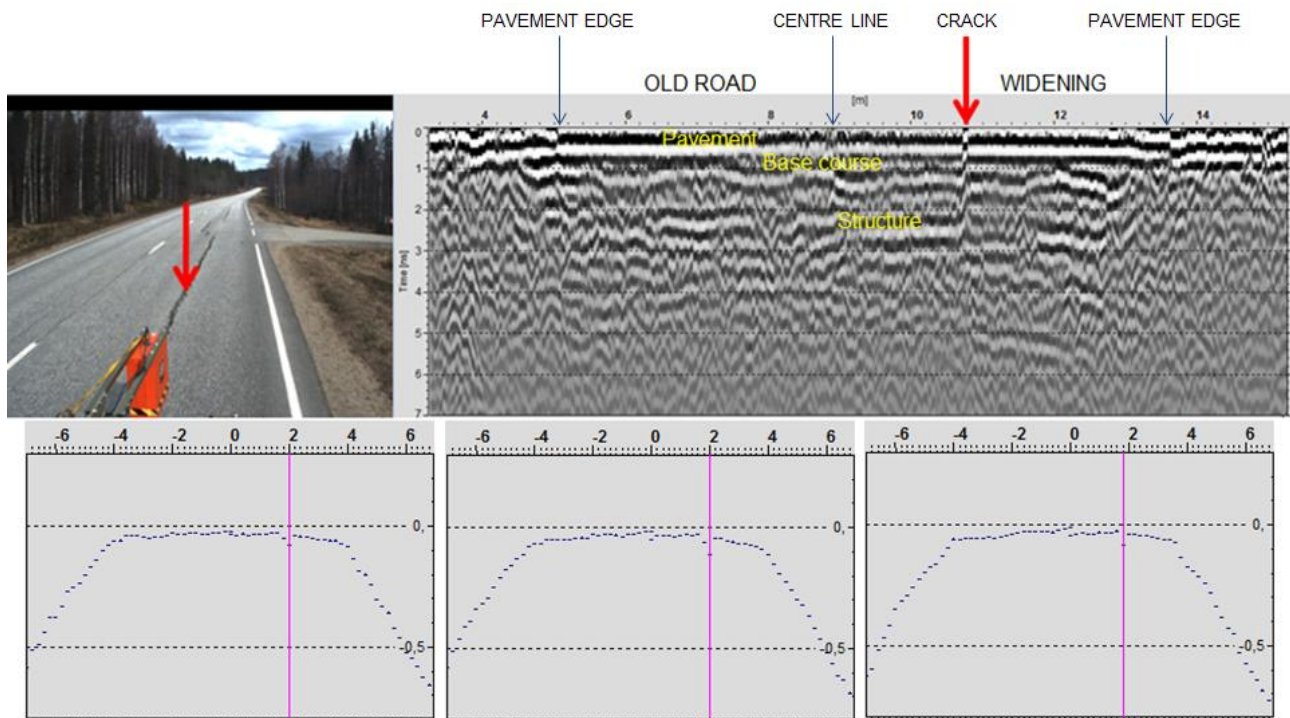


Figure 4.1_13. An example case from Road 75 showing a discontinuity and thickness difference between the old and new parts of the widened structure. The top field shows the 400 MHz GPR cross section and lower field the laser scanner cross section profiles from the same location at 10 m intervals (the one in the middle is from the red arrow location). The crack is clearly visible on the cross section profiles also. Drainage problems from an adjacent private access road might have partly triggered the distress process.

The photograph in Figure 4.1_13 shows that the distress problem could also be associated with the presence of a private access road junction. ROADDEX research has shown that drainage problems with access road culverts can cause consequential problems to the adjacent main road. An example section showing the correlation between damages and the presence of access road exits is given in Figure 4.1_14. This Figure shows that the pavement damages in Direction 1 are located close to private access roads junctions and bus stops, which supports the findings made during the ROADDEX drainage research. More information on this topic can be found from the extensive E-Learning package "Drainage of Low Volume Roads" available on ROADDEX website (<http://www.roadex.org/index.php/e-learning>). From this it can be concluded that the failures in the widened road structures, in otherwise well performing road drainage sections, have been due to water being trapped in the roadside ditches by clogged private access road culverts and infiltrating into the road structures.

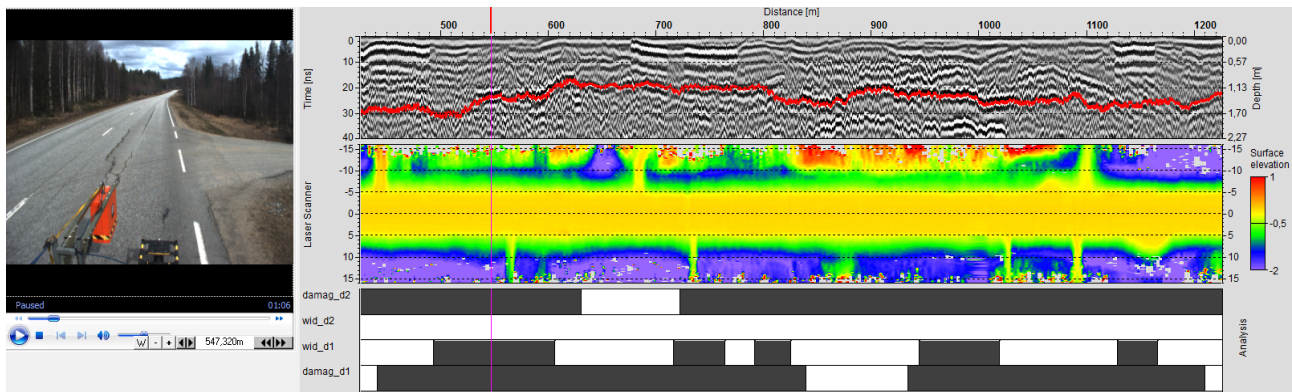
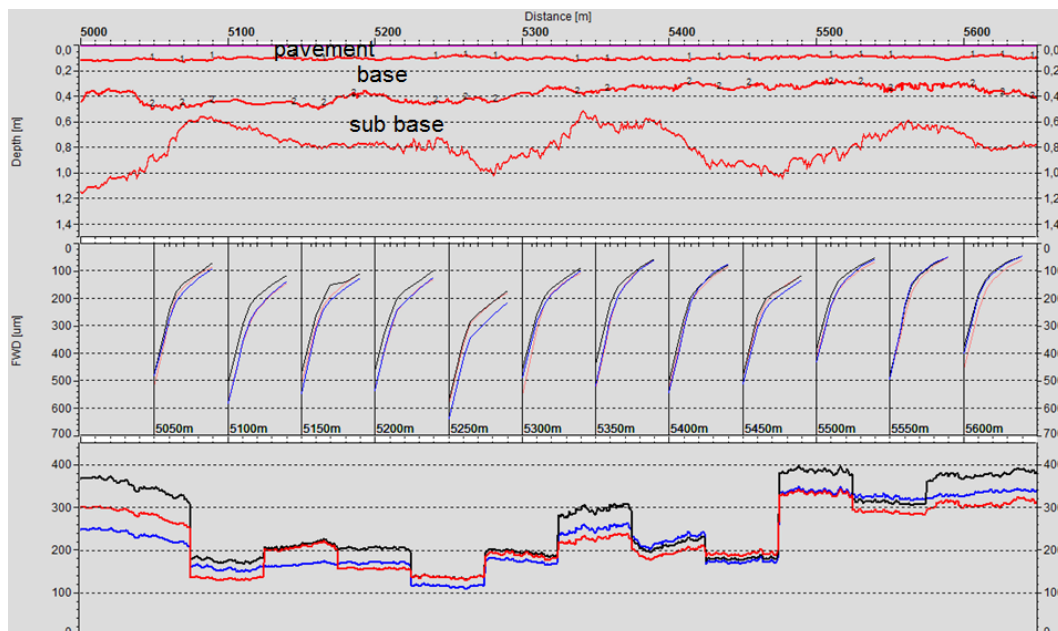


Figure 4.1_14. Example section showing the correlation between damages and the locations of access road exits. The top field shows the 400 MHz GPR longitudinal section, the middle field gives the relative height map and the lowest field presents the pavement distress analysis results. Damage code “damag_d1” and d2 mean the location of pavement damages in Direction 1 and Direction 2 respectively, and codes “wid_d1” and d2 indicate damages that can be related to road widening. In this case these damages related to road widening only exist in Direction 1.

On this road a survey was also carried out to determine if the edges of the road were weaker than the centre i.e. if there were changes in the stiffnesses of the road structures. For this FWD tests were performed on selected sections. Three points were measured at each road chainage; on each edge, and one from the centre (between the wheel paths in the right lane). Figure 4.1_15 gives an example of data from these surveys. The top window records the interpreted structure thicknesses. The next window displays the FWD deflection bowls from the centre (between wheel paths) and both edges of the road. Finally, the bearing capacities calculated from each of the FWD data sets are presented in the last window. The black line is the bearing capacity on the centre of the road, the red line is the left edge and the blue line is the right edge. On Road 75 the edges of the road were not significantly weaker than the road centre. Only slightly higher bearing capacity values were obtained from the centre at certain locations. On the other hand the calculated bearing capacity values were surprisingly low for this road class and this explains the high amount of pavement distress.



black = center, red = left, blue = right

Figure 4.1_15. Example data from Road 75 showing the interpreted structures, FWD deflections on the centre and both edges of the road, and the calculated bearing capacities.

4.2. FIELD SURVEYS IN SWEDEN

4.2.1. Ohtanajärvi, Road 857

This road was a typical example of a road that had been widened and upgraded from an old gravel road. The structure could be also called a “light widening”, similar to Hw 9 in Finland, as the widening only comprised approximately 0.5 m wide and 0.5 m thick to both road shoulders. A general view of the condition of the road is shown in Figure 4.2_1. This road had been patched several times and the road width varied. Figure 4.2_2 shows the laser scanner survey data from the site. The first window shows the laser scanner emission map indicating multiple damages and patches across the road. The laser scanner height map is given in the second window. Seven laser scanner cross section profiles are displayed on the bottom. The red lines over the emission and height data show the locations of the cross section profiles. It can be observed from these laser scanner cross sections that the road has severe rutting problems and that the road is tilting to the left, especially on the section between 150 m and 340 m.



Figure 4.2_1. General condition of the Ohtanajärvi road at 350 m. See water on the pavement in the left lane.

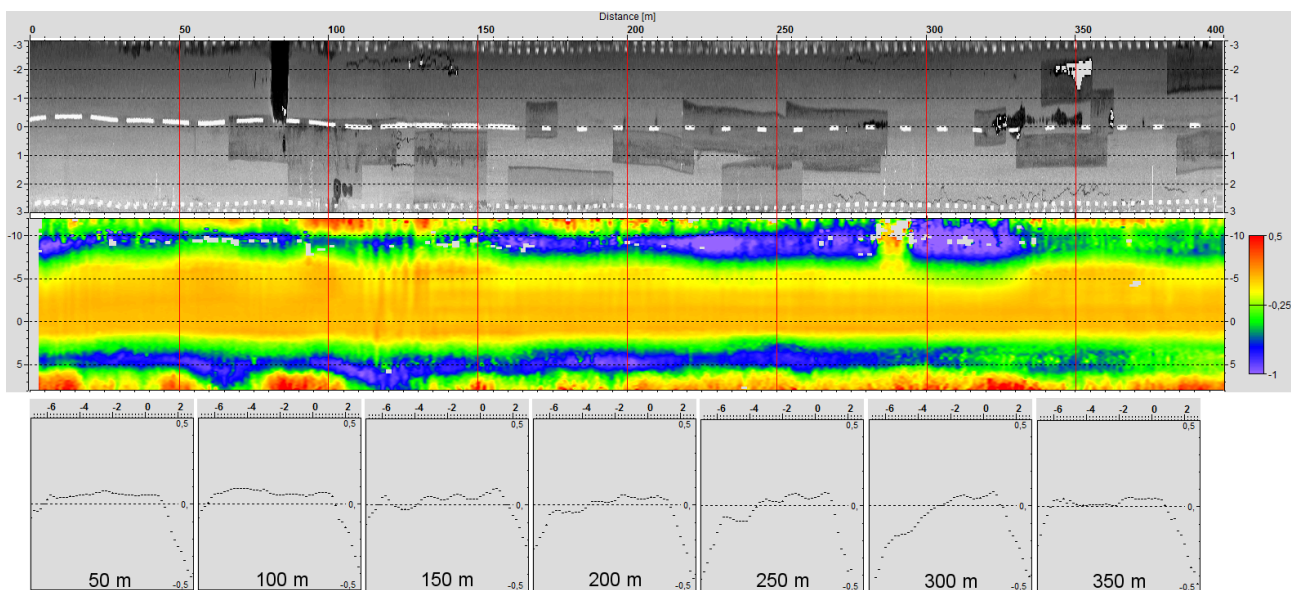


Figure 4.2_2. Laser scanner data from the Ohtanajärvi road.

Figure 4.2_3 presents an analysis of the falling weight deflectometer data from the Ohtanajärvi road section. The first window presents the FWD deflection bowls. The second window shows the

surface curvature index (SCI, red bars), the base curvature index (BCI, blue bars) and the E2 bearing capacity that is obtained from the FWD measurement (white bars). The red dashed line shows the limit for weak SCI value and where Mode 1 rutting problems start. The light blue dashed line shows the limit for BCI value where Mode 2 rutting problems start to appear, and the dark blue dashed line shows the limit for very weak BCI value. The third window presents the pavement strain value calculated from FWD measurements. The black dashed line shows the limit for a weak strain value. The subgrade moduli are displayed in the bottom window with blue bars.

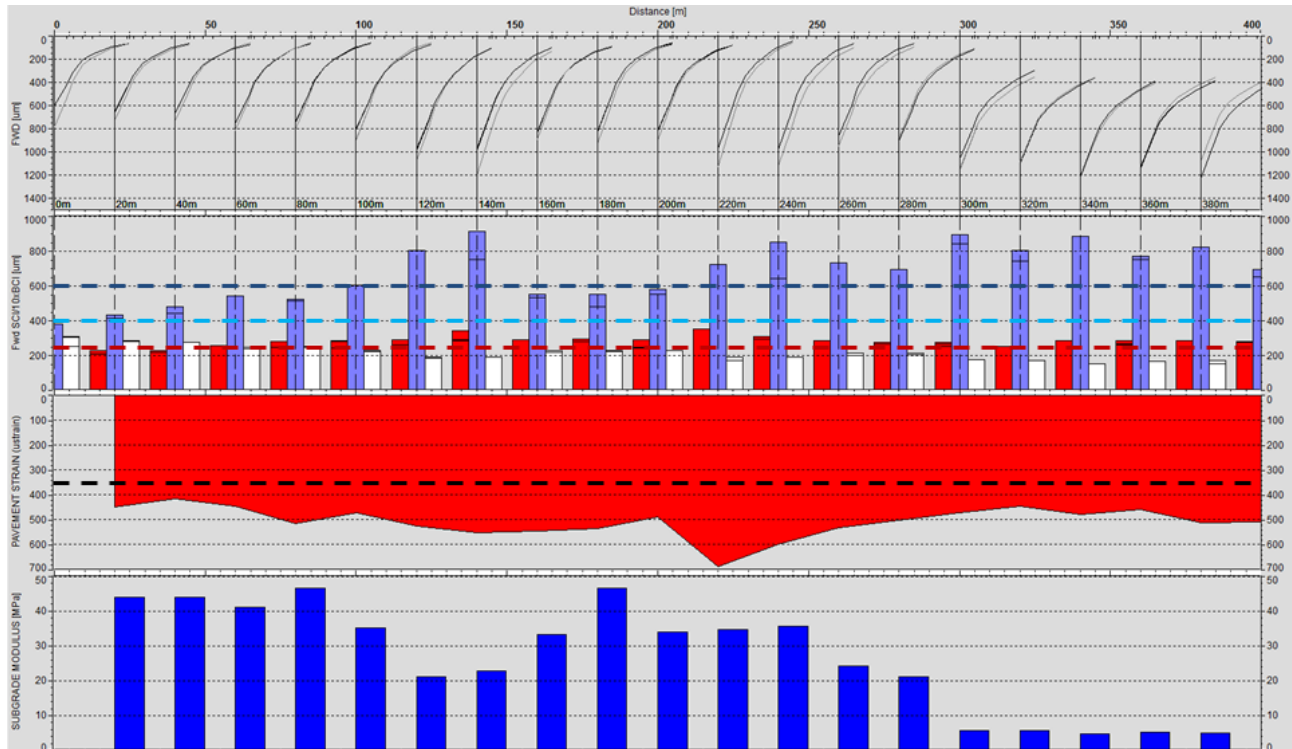
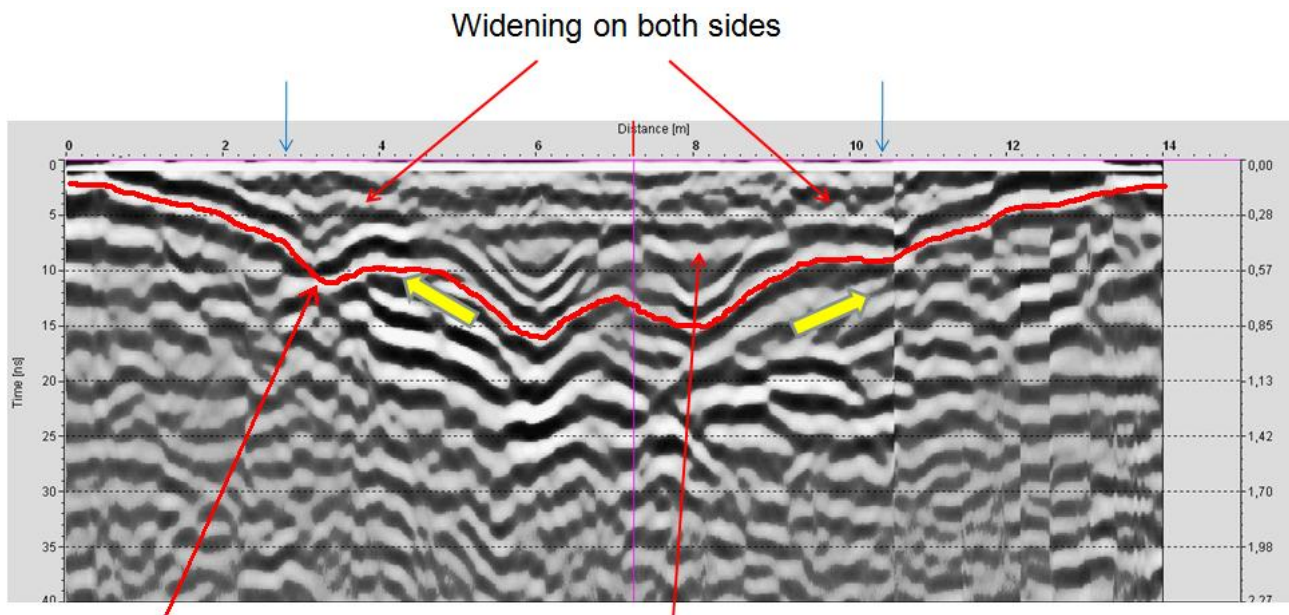


Figure 4.2_3. FWD analysis data from the Ohtanjärvi road

The FWD maximum deflections in the section are quite high, which tells that the subgrade soil is soft and that the road is weak. This can be seen also from the BCI values that are mainly around 60 – 80, which can be regarded as poor values. The road has very high risk for Mode 2 rutting. The high risk for Mode 2 rutting is verified with low subgrade moduli values, especially at the end of the test section. The SCI values and calculated pavement strain is high. This also indicates a risk for Mode 1 rutting.

All these findings are clear indicators of Mode 2 rutting, which can be confirmed from the GPR cross section shown in Figure 4.2_4. The old gravel road with Mode 2 rutting can be seen clearly below the new structures. Spring thaw weakening and Mode 2 rutting causes the soft subgrade soil to flow from beneath the road to both sides. This leads to deformations and unwanted widening of the road. The road has been widened on both sides but it has also widened by itself, and the widening is still going on.

It can be concluded that, unlike the Hw 9 in Finland, the “light widening” structure on the Ohtanjärvi road section has not been working. This has been due to the old road being too weak already in the beginning. It should have been strengthened also during the widening. Frost action also has a major role in the damage process in the Ohtanjärvi test section.



Bottom of road structures Old gravel road with mode 2 problems

Figure 4.2_4. Soft subgrade soil is flowing from beneath the road to both sides (yellow arrows) causing deformation and unwanted widening of the road. The GPR data also shows that the old gravel road under the widened road is suffering from Mode 2 rutting. The blue arrows at the top indicate the road edges.

4.2.2. Salmi, Road 392

The Salmi test section offers an example of a road with a higher quality rehabilitation and widening. Generally this road had been performing very well, although there had been some reflection cracks. Figure 4.2_5 shows the general condition of the road and it is very good. In 2010 the road had a new overlay on the road and only very few distresses could be seen.



Figure 4.2_5. General condition of the Salmi road at chainage 200 m.

Figure 4.2_6 shows the falling weight deflectometer analysis data from the Salmi road. From the data it can be observed that the road structure is strong. The FWD maximum deflections are quite low and subgrade moduli values very high, except from the first 120 m where the subgrade is slightly weaker, but still not very soft. The BCI values are mainly around 20, which is a good value. Also the calculated pavement strain is at an acceptable level, so the road structure is performing very well.

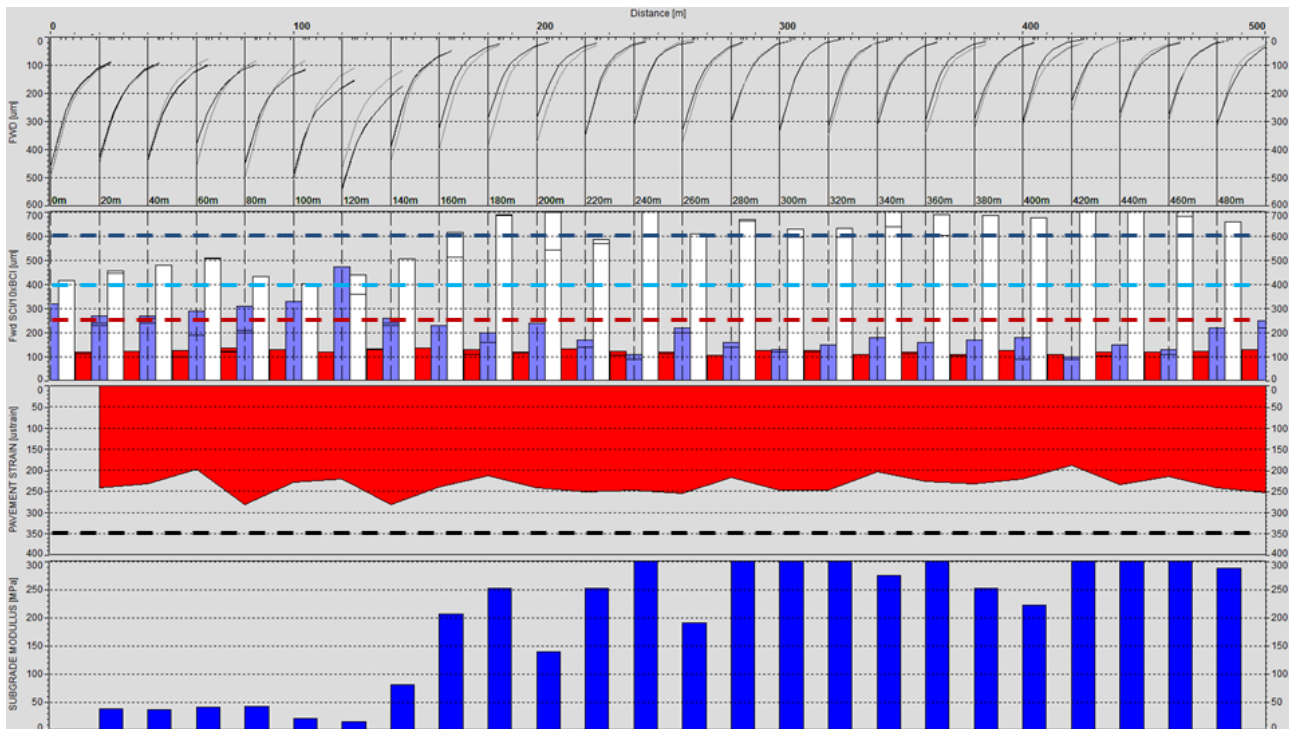


Figure 4.2_6. FWD analysis data from the Salmi road. The top window presents the FWD deflection bowls. The second window shows the surface curvature index (SCI, red bars), the base curvature index (BCI, blue bars) and the E2 bearing capacity that is obtained from the FWD measurement (white bars). The red dashed line shows the limit for a weak SCI value. The light blue dashed line shows the limit for BCI value after which it can be regarded as questionable, and the dark blue dashed line shows the limit for a very weak BCI value. The third window presents the pavement strain value calculated from FWD measurements. The black dashed line shows the limit for poor strain value. The subgrade moduli are displayed in the last window with blue bars.

From the laser scanner height map and the cross section profiles, presented in Figure 4.2_7, it can be noted that the road surface is generally very even and no rutting can be observed. The ditches are deep enough and drainage seems to be in good condition. The red lines over the data show the locations of the cross section profiles.

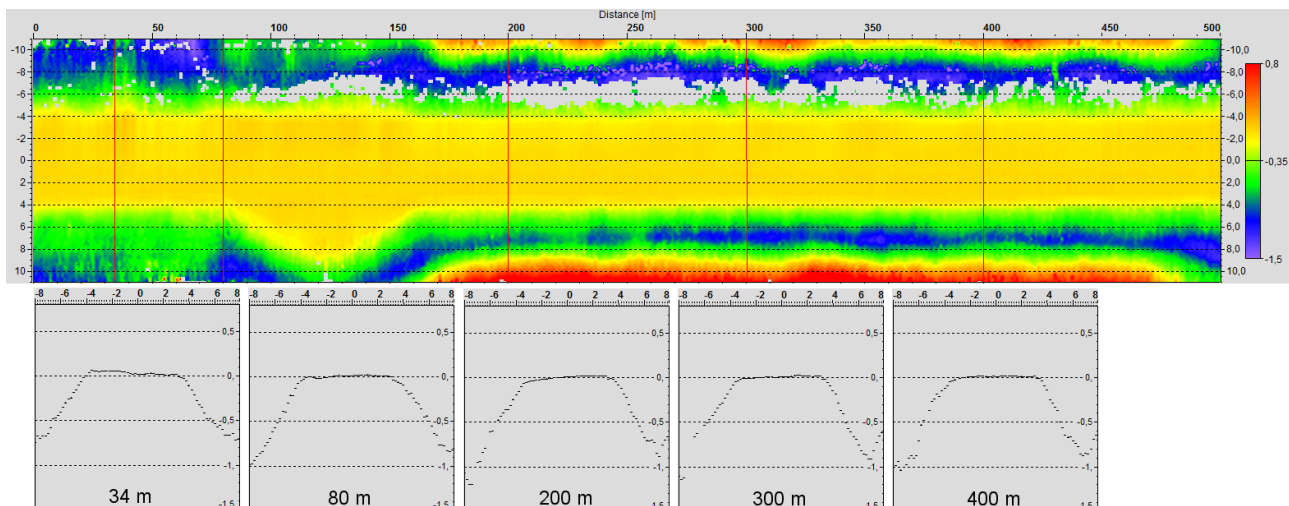


Figure 4.2_7. Laser scanner data from the Salmi road

However, one clear construction error that causes reflection cracks was found on this test section, when it was surveyed the first time some ten years ago. An old bituminous pavement layer had been left inside the structure during the upgrading and widening of the road. As a consequence of this “sandwich structure”, reflection cracking took place on the road surface at the location where the pavement edge ends and the new widened part begins. Figure 4.2_8 shows the GPR cross

section and the crack in 2000. Figure 4.2_9 shows the same location in 2010 and the same reflection crack is still visible, even though the road had been paved since. The first laser scanner cross section profile in Figure 4.2.7 shows this location (34 m) and the observed unevenness. This type of sandwich structure must be avoided when designing a widening or any other kind of road rehabilitation. The old bituminous pavement layers must be removed, or crushed and homogenized, before construction.

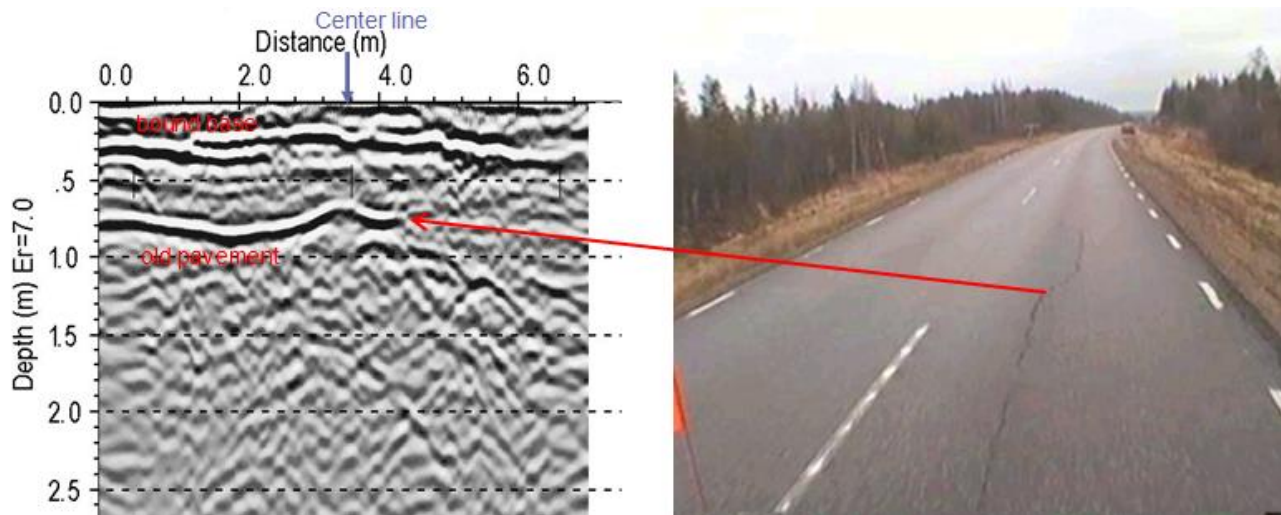


Figure 4.2_8. Old bituminous pavement layer inside the road structure on Salmi road in 2000.



Figure 4.2_9. The same reflection crack as in previous figure is still visible on the road in 2010.
See also edge cracking that was not so bad in 2000.

4.2.3. Karrbäck, road 767

The Karrbäck road gives an example of a widened and upgraded road on very soft silty subgrade. The GPR cross section from the old data shown in Figure 4.2_10 shows that the road has been widened to left side before being upgraded. It can also be noted that the overall structure thickness is still relatively thin, 0.4 – 0.6 m.

At the time of the survey in 2010 there had been a new overlay on the road, so the pavement surface condition at the time was relatively good, as it can be seen from Figure 4.2_11. But the photograph also shows that the ditches are very shallow and that the drainage is not working properly.

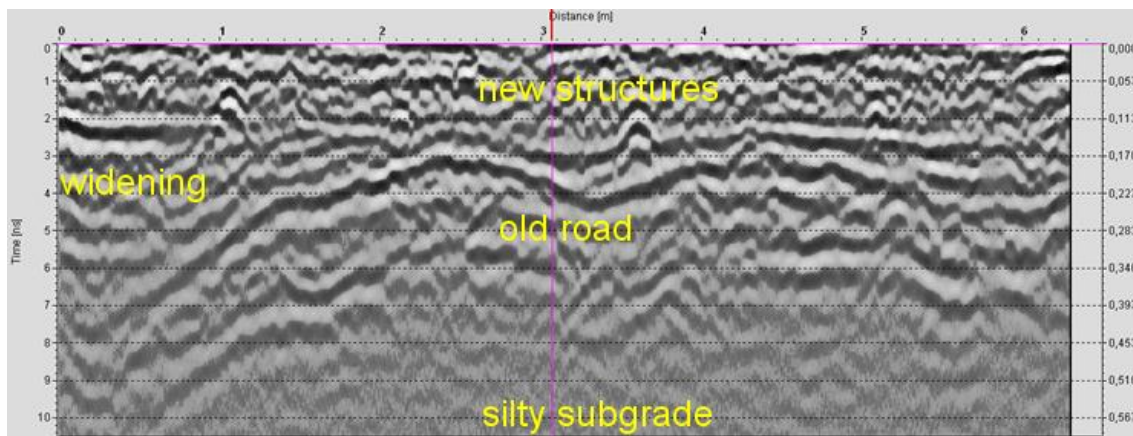


Figure 4.2_10. Karrbäck GPR cross section, 250m measured in 2000.



Figure 4.2_11. General condition of the Karrbäck road at chainage 250 m. Observe the shallow ditch depth.

Figure 4.2_12 shows the laser scanner survey data from the site. The first window shows the laser scanner emission map and it can be observed from the data that the pavement surface condition is quite good. From the laser scanner height map, presented on the second window, the shallow ditch depth can be clearly seen. The depth gets shallower towards the end of the test section. Seven laser scanner cross section profiles are displayed in the bottom window. The red lines over the emission and height data show the locations of the cross section profiles. It can be noted from the cross sections that the road is tilting to left, which is the widening side. Rutting has also taken place, especially on the widening side and on both road shoulders. The cross section series also displays very nicely the ditch depth getting shallower and shallower.

The effect of pumping and insufficient drainage can also be seen from the measured pavement dielectric value (ϵ_r), displayed on the top window of Figure 4.2_13. From that point where the ditch gets very shallow there is a clear rise in the pavement ϵ_r level. This is a clear indication of excess water in the pavement. Water is pumping through the pavement layers.

Figure 4.2_13 also shows the FWD analysis data from the road. The second window presents the FWD deflection bowls. The third window shows the surface curvature index (SCI, red bars), the base curvature index (BCI, blue bars) and the E2 bearing capacity that is obtained from the FWD measurement (white bars). The red dashed line shows the limit for a weak SCI value. The light blue dashed line shows the limit for problematic BCI values, and the dark blue dashed line shows the limit for a very weak BCI value. The fourth window presents the pavement strain value calculated from FWD measurements. The black dashed line shows the limit for weak strain value. The subgrade moduli are displayed in the last window with blue bars.

The FWD maximum deflections are very high, which indicates that the subgrade soil is soft and that the road structures are extremely weak, worse than on many weak gravel roads. The soft subgrade is verified from the calculated subgrade moduli values that range from 2 to 4, which are extremely weak. All the base curvature index (BCI) values are approximately three to four times higher than the critical limits for Mode 2 rutting, so they can be regarded as extremely poor values. Also the calculated pavement strain and surface curvature index (SCI) values are very high, so there are problems also on the top part of the structure.

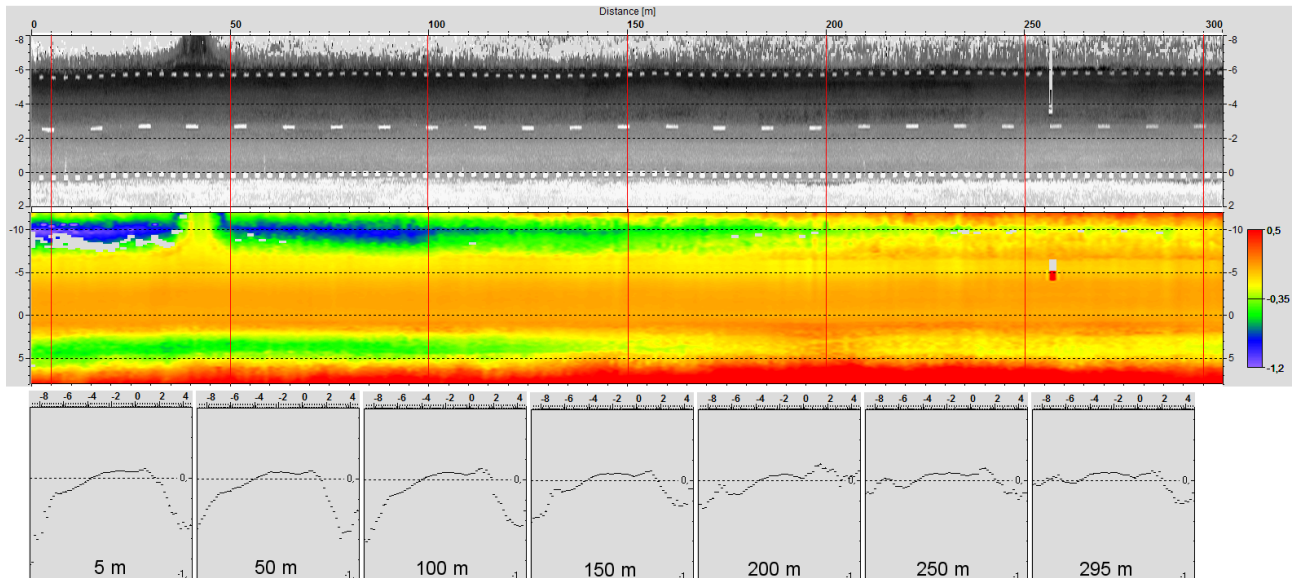


Figure 4.2_12. Laser scanner data from the Karrbäck road

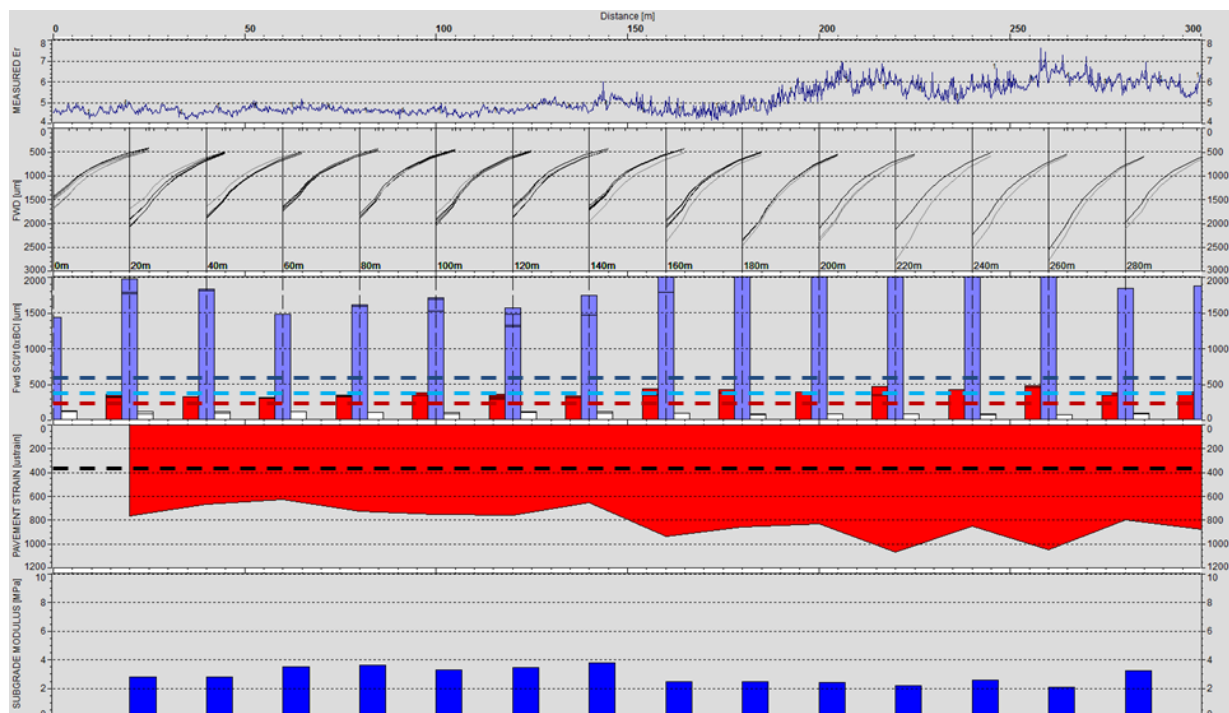


Figure 4.2_13. Pavement dielectric value and FWD analysis data from the Karrbäck road

The road had been widened on the left side and there was some settlement and rutting taking place on that side, but the main problem with this road section was not related to the widening. The whole road was settling into the very soft silty subgrade. This phenomenon was made even worse by the fact that the ditches were filled, which caused the drainage to be ineffective. The data also showed that the road would fail badly in the near future and that the strengthening measures on the road had not been adequate enough.

4.2.4. Lapträsk, road 398

This test section gives an example of a road where steel reinforcement can be used to prevent longitudinal cracking. The road had been widened already earlier, but there were longitudinal cracking /frost cracking) and edge failures. After that steel nets had been installed. Figure 4.2_14 shows the road surface condition at the time of the survey in 2010 and it was very good.



Figure 4.2_14. General condition of the Lapträsk road at chainage 150 m.

Figure 4.2_15 presents the GPR and laser scanner survey data from the site. The first window shows the longitudinal GPR profile from the left edge of the road and the second window shows the right edge. It can be observed that for the first 95 m there is reinforcement only on the left shoulder and after that the steel nets cover the whole cross section width of the road. This can be confirmed also from the GPR cross sections shown in Figure 4.2_16. The left cross section is from the beginning of the test section and the right cross section is from the chainage 200 m.

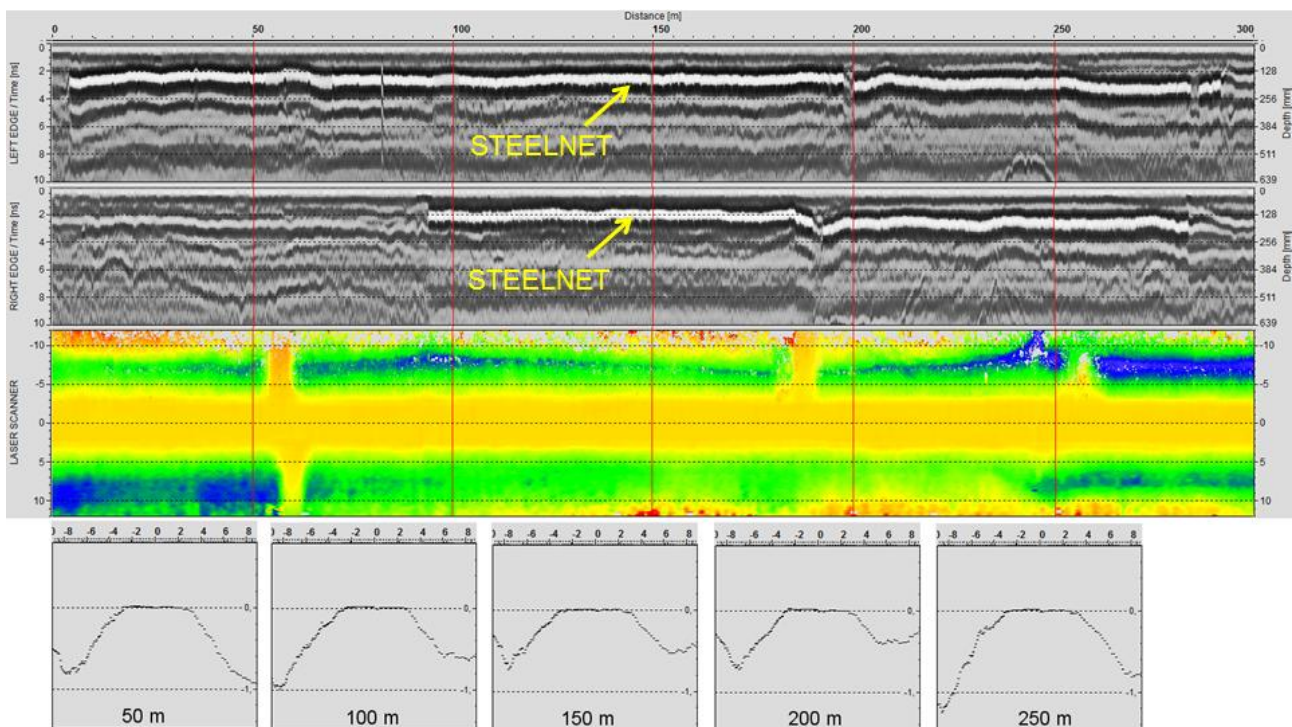


Figure 4.2_15. GPR and laser scanner data from the Lapträsk road

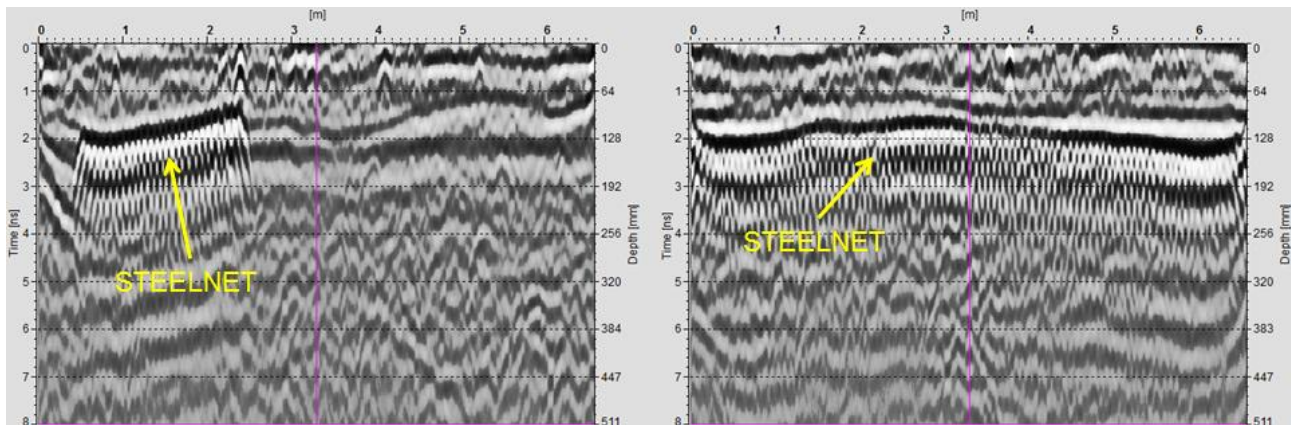


Figure 4.2_16. GPR cross sections showing that in the beginning of the test section the reinforcement is only on the left lane and after that the steel nets cover the whole cross section width of the road. The left cross section is from the beginning of the test section and the right cross section is from the 200 m pole. See also that the steel reinforcement does not reach to the pavement edge in the left cross section.

Figure 4.2_17 shows the correlation between the depth of the steel reinforcement and the rut depth on the Lapträsk test section measured in 2000. The results clearly show that if the steel net is not deep enough, it cannot properly prevent the rutting from taking place. Other experiences from the ROADDEX project have shown that the most effective depth for the steel reinforcement inside the structure is approximately 250 mm. Because of the new overlay since the 2000 survey, the steel nets are now deeper in the structure. The current depth of the reinforcement interpreted from the GPR data varies from 13 cm to 18 cm, so now they starting to be deep enough to ensure to road will perform well.

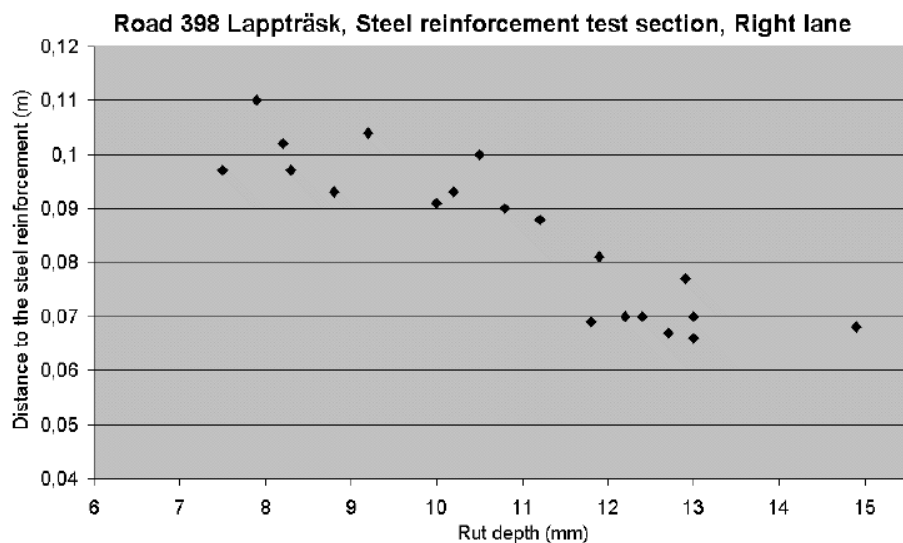


Figure 4.2_17. Correlation between the depth of the steel reinforcement and the rut depth on the Lapträsk road in 2000

From the laser scanner height map and the cross section profiles, presented in Figure 4.2.15, it can be seen that the road surface is very even and no rutting can be observed. Drainage seems to be in relatively good condition also, except that the right ditch is too shallow from 100 m to 250 m. The outlet ditch on the right hand side is clogged which can be seen as poor subgrade moduli at chainage 200 m (figure 4.2_18). The red lines over the data show the locations of the cross section profiles.

Figure 4.2_18 shows the FWD analysis data from the Lapträsk road. The SCI values are well below their critical limits and the pavement strain is also on acceptable level. The BCI values are just below limit value of 40 μm indicating that the reinforcement is strengthening the road over the

frost susceptible subgrade. Generally, the reinforced road structure is performing quite well, and there should not be any major problems in the near future especially if the drainage is improved.

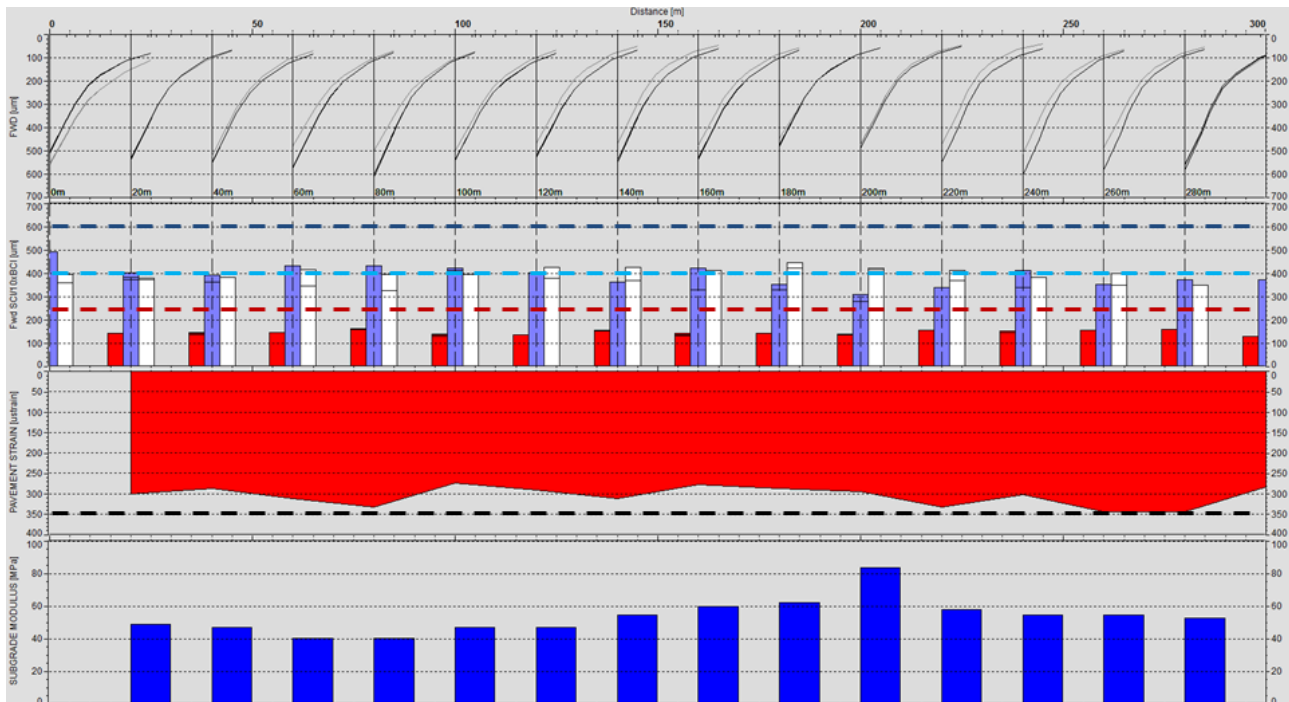


Figure 4.2_18. FWD analysis data from the Lapträsk road. The top window presents FWD deflection bowls. The second window shows the surface curvature index (SCI, red bars), the base curvature index (BCI, blue bars) and the E2 bearing capacity that is calculated from the FWD measurement (white bars). The red dashed line shows the limit for a weak SCI value. The light blue dashed line shows the limit for problematic BCI values, and the dark blue dashed line shows the limit for really weak BCI values. The third window presents the pavement strain value calculated from FWD measurements. The black dashed line shows the limit for weak strain value. The subgrade moduli are displayed in the last window with blue bars.

4.3. FIELD SURVEYS IN NORWAY

4.3.1. Engerud, road 855

This road section was selected as a ROADDEX test site in 2001 because it was showing severe longitudinal reflection cracking. Composite glassfibre fabric had been used to prevent cracking but this structure had already failed by 2000.

Road 855 is an old road that was paved several times in the 1970's, 1980's and 1990's. In 1995 the old pavement was stabilized to a depth of 60 mm. The road structure had a 40 mm wearing course made of soft asphalt. The composite glass fibre fabric was located on top of 40 - 60 mm of the stabilized old pavement layers. The sub-base was made of gravel and the subgrade soil was frost susceptible silt. The road had generally been working quite well except for longitudinal cracking problems.

Figure 4.3_1 shows a photographs from the Engerud road taken in 2001 and in 2011. The same longitudinal crack can be seen in both photographs. The reason for the failure crack can be seen in the GPR cross sections presented in figure 4.3_2. The crack is located on the joint between the old road and the widening. The road structure thickness on the widening side is much thinner than on the old road side and the subgrade beneath is frost susceptible silt. As a consequence the frost behaviour is different and a reflection crack has formed due to traffic loading, settlement and frost action.

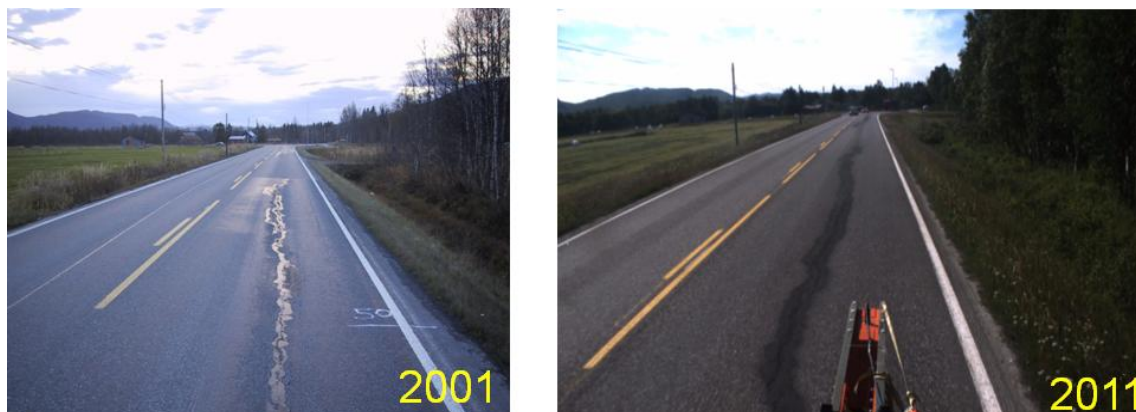


Figure 4.3_1. Engerud test road condition in 2001 and 2011

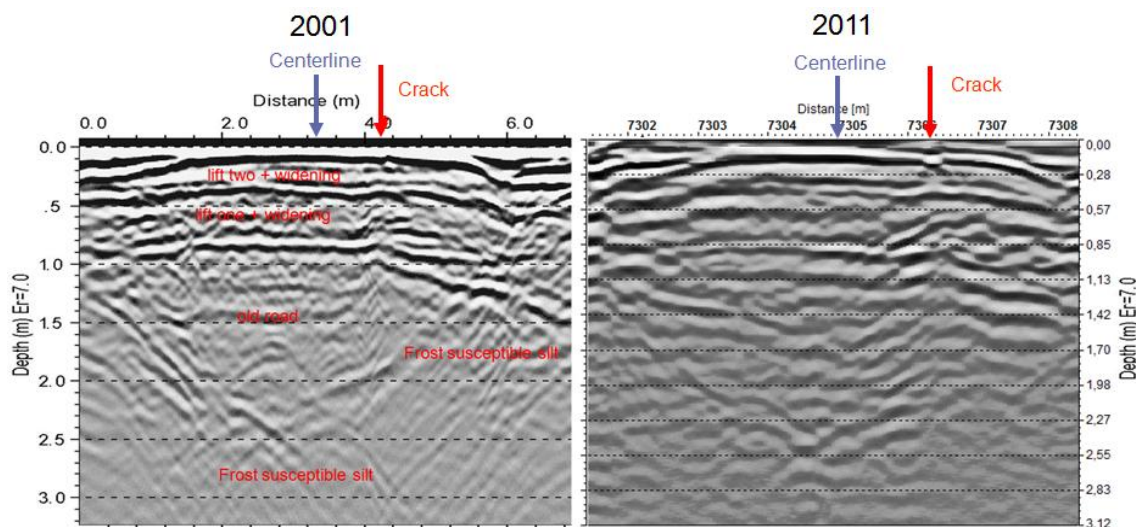


Figure 4.3_2. Engerud 400 MHz GPR cross section in 2001 and 2011

Laser scanner data from the Engerud road section is presented in figure 4.3_3. The first window shows the laser scanner emission map, height information is given in the second window, and four cross section profiles are displayed on the bottom. The red lines over the emission and height data show the locations of the cross section profiles. The pink line on each cross section shows the location of the reflection crack and data shows a clear groove indicating shear problems. Laser scanner cross section profiles indicate that the rut depth is higher on the widened side of the road. From the GPR cross sections it can also be seen that there are thicker pavement layers on both edges of the road, especially on the widening side. These facts indicate that some Mode 2 rutting has also been taking place in the road structure / subgrade interface.

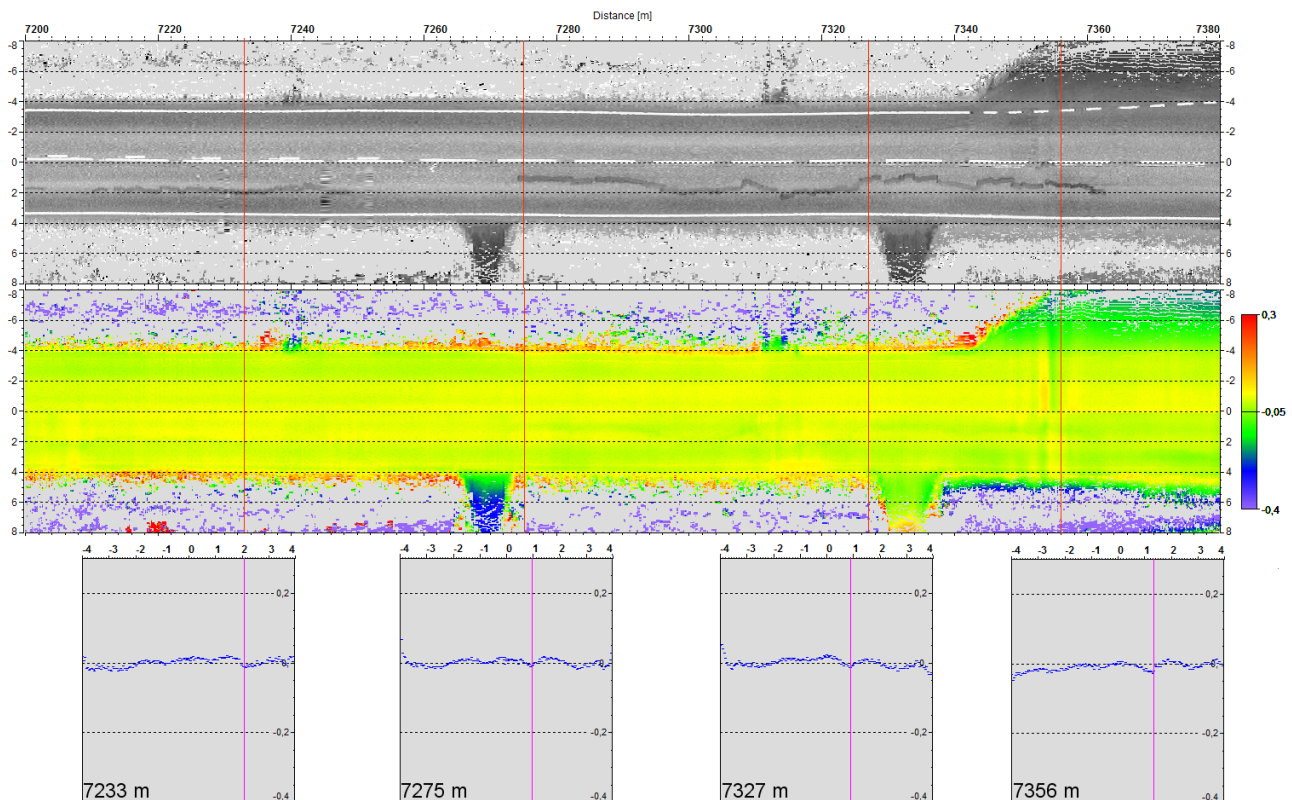


Figure 4.3_3. Laser scanner data from the Engerud road section

The glassfibre strengthening has not been able to prevent the reflection crack forming. It can be concluded that glassfibre is not an adequate strengthening method, if there are vertical shear forces taking place in the widening joint.

4.3.2. Kjosemyra, road 858

The Kjosemyra road section is an example of a road constructed on peat and later widened. The road section surveyed was an old road that had been paved several times since the late 1970's. The road structure had a relatively thick asphalt layer on the top because of the several overlays due to settlement. The base and sub-base were made from non-frost susceptible gravel. The subgrade soil was peat.

The road had been widened on the left side and later a bicycle path had been built on the right side. There had been severe peat settlement problems in the transverse road section (Figure 4.3_4) incurring settlements in the widened area of between 15 and 30 cm. These did not result however in major roughness problems. Prior to the survey improvements had been made as seen in the photograph in Figure 4.3_5 from year 2011.

The settlement in the widened area can be seen from the GPR cross sections shown in Figure 4.3_6. The left cross section is from the 1.5 GHz antenna showing the top part of the structure. The right cross section presents the 400 MHz antenna data which reaches deeper. The peat

settlement can be clearly observed, especially on the widening side on the left. But settlement can also be seen on the right edge of the road, which is a consequence of the construction of the bicycle path beside the road.



Figure 4.3_4. Peat settlement on Kjosemyra road in 2001



Figure 4.3_5. Road condition in 2011

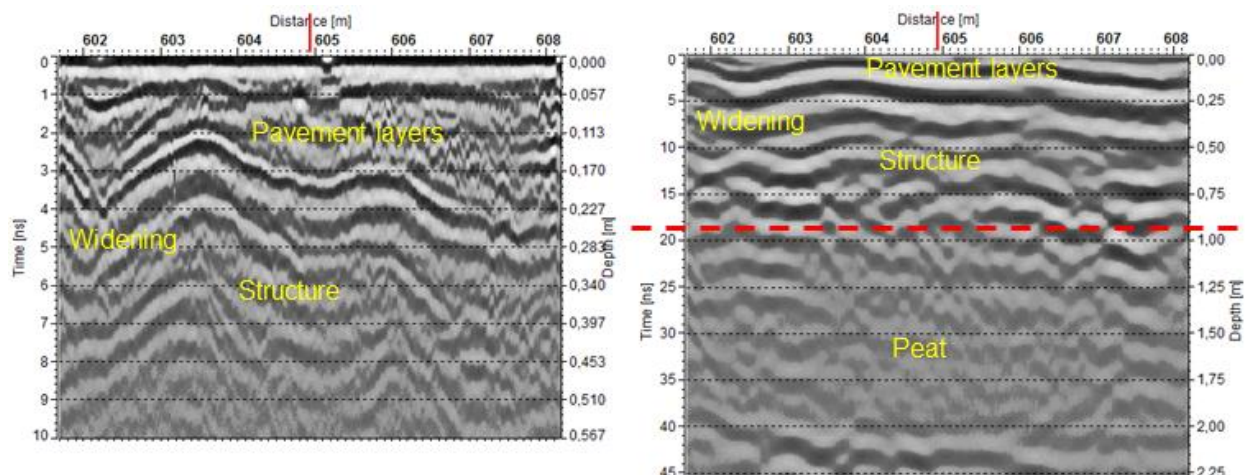


Figure 4.3_6. GPR cross sections (left: 1.5 GHz, right: 400 MHz) showing peat settlement on the Kjosemyra road

The good news that can be seen from the 400 MHz cross section is that the bottom of the road structures on the widening side is reaching the same depth level as the old road side (red dashed line). From this it can be concluded that the greatest part of peat consolidation beneath the widened area has now taken place. The peat stiffness is on the same level on the road centre and on the widened area, and major settlement should not take place anymore.

4.3.3. Tennes, road 859

This road gives an example of a low traffic volume road, widened and upgraded from old gravel road, with severe uneven frost heave and bearing capacity problems. The road is also located on a side sloping hill.

The old road structure consists of low frost susceptible gravel. Before paving the road in 1986, 150 mm of crushed gravel was compacted on top of the old gravel road. The newest wearing course comprises soft bitumen asphalt. The subgrade is mainly low frost susceptible gravel and moraine. The road condition was very bad in 2001, especially on the old road side (right), while the widened side (left) was slightly better (Figure 4.3_7.). The photograph in Figure 4.3_8 from 2011 shows that the road had been repaved since 2001, and that a reflection crack had formed between the old and widened area. In 2011 the drainage condition was much worse than 2001.



Figure 4.3_7. Road condition in 2001



Figure 4.3_8. Road condition in 2011

Examples of GPR cross sections are given in figure 4.3_9. The left cross section is from the 1.5 GHz antenna showing the top part of the structure. The right cross section shows the 400 MHz antenna data which reaches deeper. On the cross sections the old gravel road can be seen clearly beneath the new base course. The road has been widened to the left, which is the uphill side, as the road is located on side sloping ground. On the 400 MHz cross section a wedge shaped embankment fill can be seen beneath the old road. On the structure - subgrade interface, Mode 2 rutting can be observed in the 400 MHz cross section.

The 1.5 Ghz cross section (left in Figure 4.3_9.) also shows shoulder deformation problems on the widened left side of the road that can be related to the drainage problems on the upper side of the road.

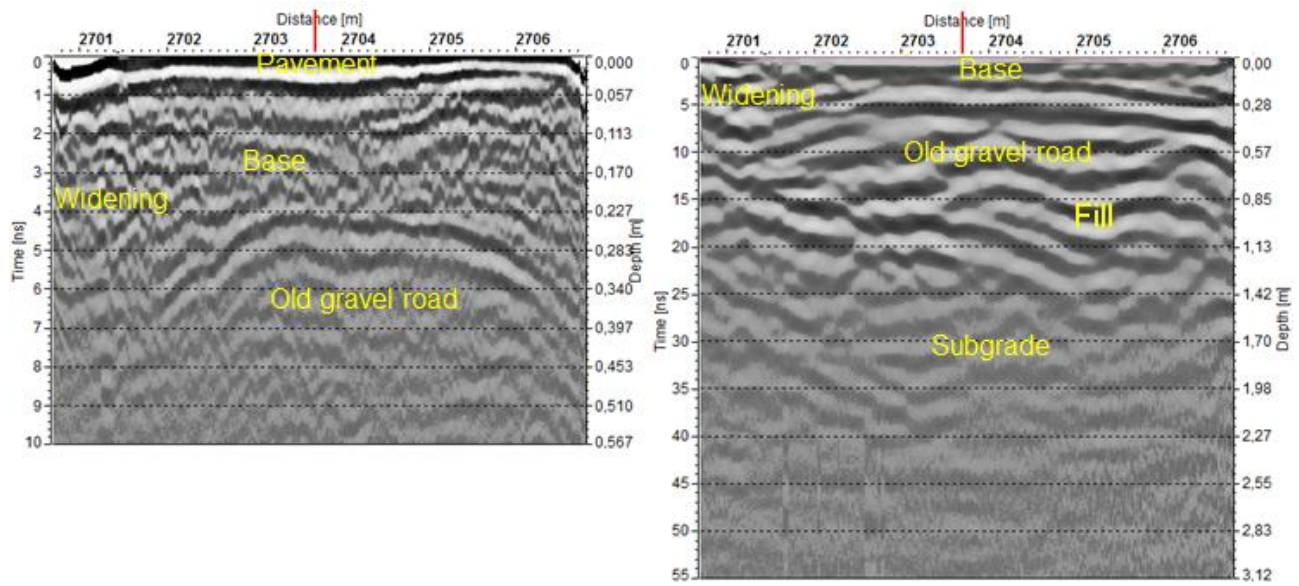


Figure 4.3_9. GPR cross sections (left: 1.5 GHz, right: 400 MHz) from Tennes road

4.4. FIELD SURVEYS IN SCOTLAND

4.4.1. Killimster Moss, road B876

History, problem diagnostics in 1999 - 2000

Road B876 at Killimster Moss in North-Eastern Highland in Scotland was one of the first sites where the ROADDEX idea of technology exchange of best practices was implemented in a full scale road test. The road over blanket bog at Killimster was built in 1930 with a reinforced concrete structure and later this was paved with bituminous pavement layers and the road was widened with traditional structures. The road had been performing quite well during the decades except that it was slowly settling down into the peat following the shape of the peat bottom. However in the 1990's the road started to fail after it became increasingly exposed to higher volumes of heavy traffic (Figure 4.4.1_1). Because of the good experiences of steel grids in the Nordic Countries in reinforcing roads resting on peat this road was chosen to be one of the first ROADDEX technology exchange test sites in Scotland.



Figure 4.4.1_1 Example of problems with Killimster road in 1999.

The site investigations in 1999 were carried out using a GPR technique to measure the layer thicknesses and perform damage diagnostics. Also a topographical survey and peat probe survey was made to calibrate the GPR surveys and these results showed that the peat thickness varied from two metres to seven metres deep. In the areas with deepest settlements the thickness of the bituminous layers over the concrete was more than 600 mm thick and the worst road sections were located on places where there was a sudden change in the depth of peat. GPR results together with drill cores showed that lower part of the bituminous pavement had severe stripping problems which were due to high hydrostatic pressures under the heavy loadings breaking the bitumen/aggregate bonds in the bituminous (bitmac) layers (Figure 4.4.1_2.). This problem was worsened by the presence of transverse cracks that were located in the areas where the thickness of the embankment was rapidly changing due to differential settlements. There was also a wide crack in the middle of the road indicating that the road was slightly widening due to transverse movement of the slab (Figure 4.4.1_3).

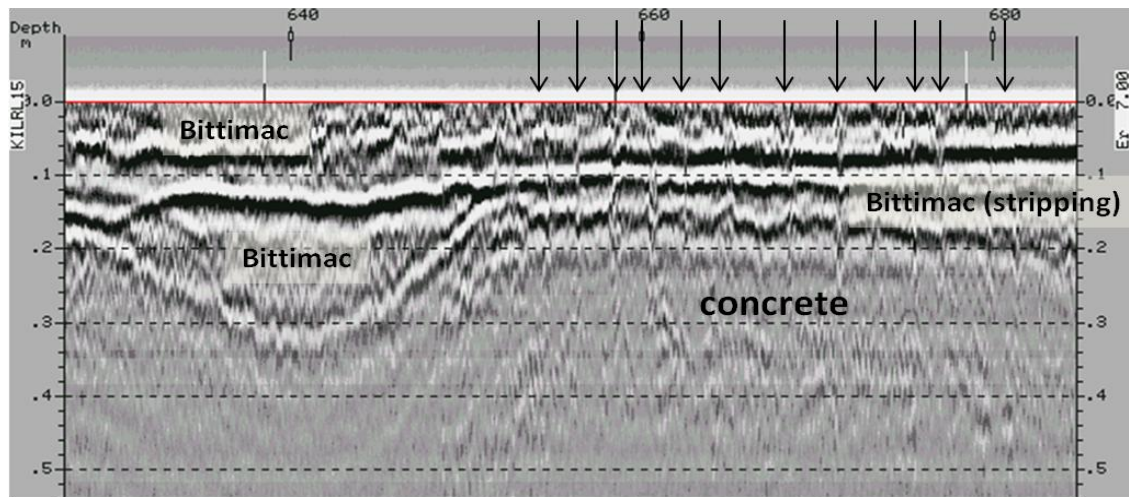


Figure 4.4.1_2 A 1.5 GHz GPR longitudinal profile over Killimster Moss. Transverse cracks going through the concrete slab and bitmac are shown with arrows. Stripping in the bitmac layers starts roughly at level of 0.1 m.



Figure 4.4.1_3 Photograph taken from a test section showing stripping on the bottom part of bituminous layers, and longitudinal cracks and transverse cracks in the concrete slab causing reflection cracking on the pavement surface.

Strengthening in 2000

Due to limited funding available the design life for the strengthened structures was agreed to be 8 years, and the structural solution requested to be as cheap as possible. In the strengthening design one of the main goals was not to increase the embankment load any further so as to cause further settlements. Because of this, and because of the severe stripping problems in the existing bituminous layers, it was decided to remove the bituminous layers down to the top of concrete. A second design brief was to widen the road on both sides of the existing concrete slab. The proposed rehabilitation and widening structure is shown in Figure 4.4.1_4.

Figures 4.4.1_5 and 4.4.1_6 show how the road construction was carried out in practice. Figure 4.4.1_7. presents the 1.5 GHz GPR survey data after the construction was finished. This shows that the steel grid was partly installed on the top of the concrete slab and partly over the bituminous base course (bitmac). Figure 4.4.1_8. shows photographs taken from Killimster Moss in 2000 after the construction, and three years later in 2003.

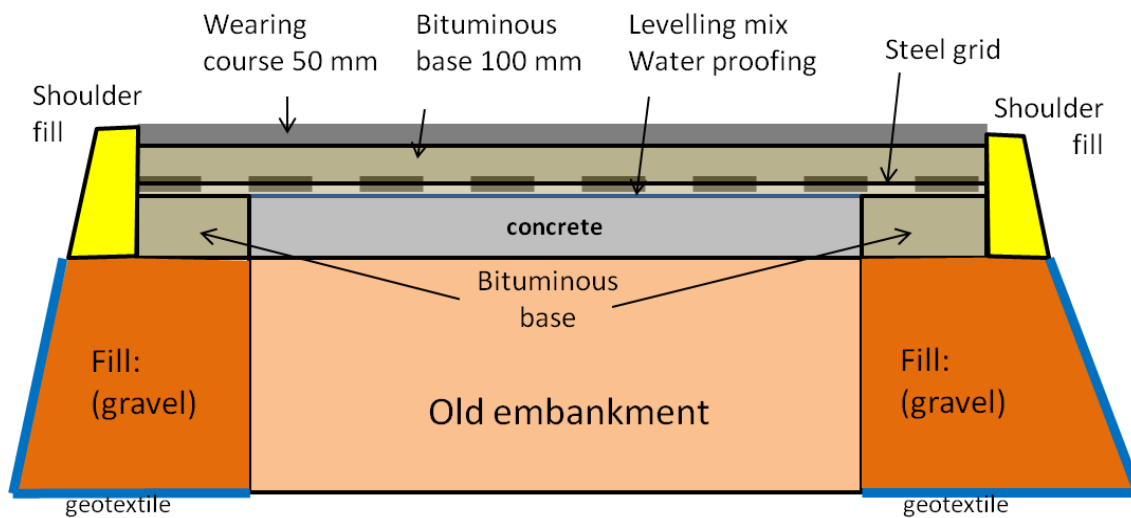


Figure 4.4.1_4. A schematic illustration of the strengthening and widening structure. Plumer modified bitumen was used in the waterproofing and levelling mix.



Figure 4.4.1_5. The widening was made first by excavating the old material down to the bottom level of old embankment (left). Then a geotextile was placed to separate the peat from the road structures and crushed unbound aggregates were compacted up to level of roughly 80-100 mm below the level of the concrete surface (middle and right).



Figure 4.4.1_6. The left photograph shows the cleaned and polymer modified bitumen sealed cracks in the concrete slab after the bitmac had been milled away. Part of the cracks were so wide that bitmac had also to be used to seal them. The photograph in the middle shows the steel grid installed on the top of the concrete slab and the widened area capped with a bituminous base. A leveling mix had to be provided on top of the concrete slab under the steel grid in some areas. The right photograph shows the bituminous base being laid on top of the steel grid.

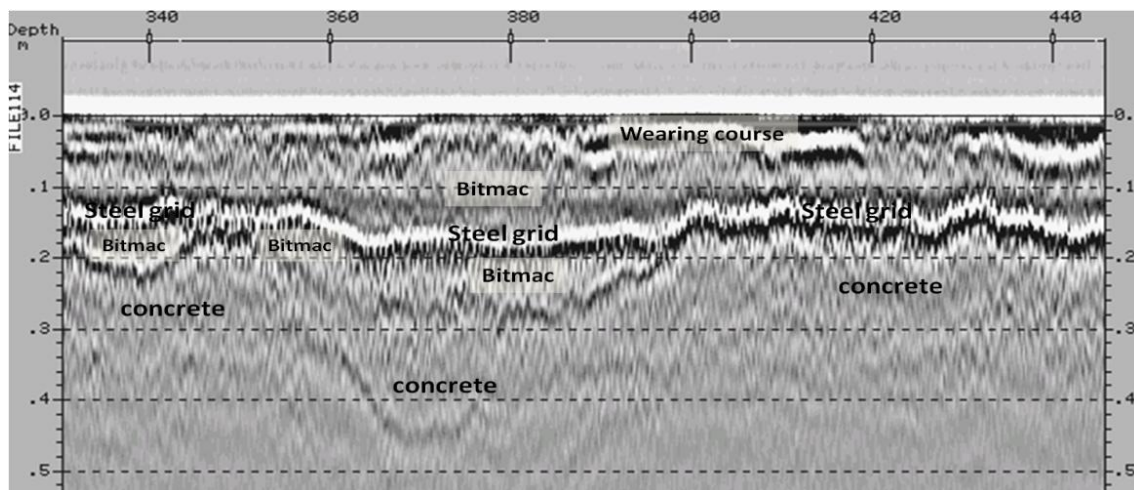


Figure 4.4.1.7. 1.5GHz GPR longitudinal profile measured over the strengthened structure. This GPR data shows that the bitmac was used to lift the grade line in the lowest spots before steel grid was installed but mainly the steel grid was installed on the top of concrete (starting from 400 m.)



Figure 4.4.1.8. B876 at Killimster Moss after road works were finished in 2000 (left) and in 2003 (right)

Follow up tests in 2011

The Killimster Moss section was monitored again in 2011 as part of the ROADDEX IV project to investigate how well the road had performed during the ten years after construction, and what were the reasons for the failures appearing on the road surface. In this work the road was first inspected visually, and a survey of the cracks was made by the Highland Council (Figure 4.4.1_9). Photographs were also taken of the sections showing distress (Figure 441.9). GPR surveys using 1.5 GHz and 400 MHz antennas were carried out and both longitudinal and cross sections were measured. In this case FWD data was collected from both the concrete slab and widened area in order to get information on any differences between the road structural stiffness. The collected data was then analysed using Road Doctor software.

The crack maps and visual inspection showed that the cracks occurred mainly on the westbound lane that was being used by the heavy traffic, but that cracks could also be found on the eastbound lane (Figure 4.4.1_9). At the start, and at the end, of the road section where peat was thinner cracks generally crossed both lanes. The photograph taken from the road (Figure 4.4.1_10) shows that cracks have appeared again on the places with differential settlements on the road ("hill tops" and valley bottoms"). The same phenomenon could be found in the year 2000 inspection. The irregular white side lines indicate lateral movements of the concrete slabs.



Figure 4.4.1_9. Example from the map of surface cracks from Killimster road in 2011, Heavy traffic is using the westbound left lane from right towards left.



Figure 4.4.1_10. The cracks in the B876 in 2011 were mainly located on sections where there were differential settlements in the peat. The wavy white line at the edge of the pavement shows that there are also lateral movements in the road structures in these sections.

Figures 4.4.1_11 and 4.4.1_12 present cross sections from the 1.5 Ghz GPR survey: “Cross Section 2” was measured at a problem section and “Cross Section 9” at a section where no damage could be seen. A main difference, that could explain why damage appear where it does, is that on the problem sections the steel grid has been installed directly on top of the concrete slab and in this case hardly any bonding has happened between the slab and the bituminous layers. The longitudinal cracks in the road centre were reflecting the lateral movements of the concrete slabs due to traffic loading.

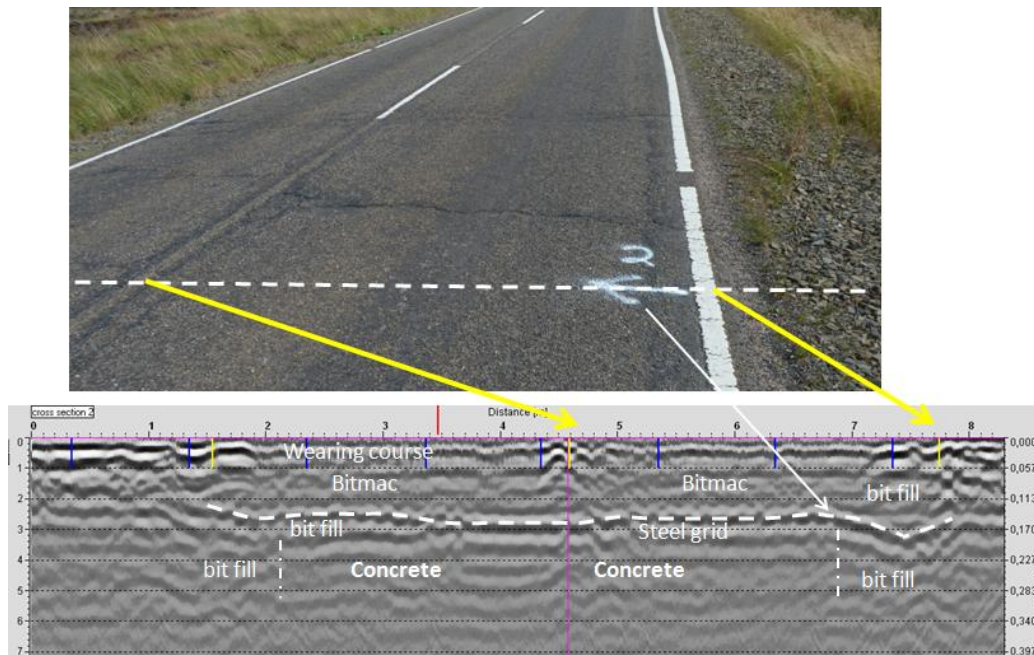


Figure 4.4.1_11. 1.5 GHz GPR cross section from Killimster Moss road with closely spaced transverse cracks (see photograph) and longitudinal cracks in road centre (left yellow arrow) and road shoulder (white arrow). In this case the steel grid was installed directly on top of the concrete slab and only a thin bituminous leveling mix could be found under the left side. The longitudinal shoulder crack reflects the location of the end of the concrete slab.

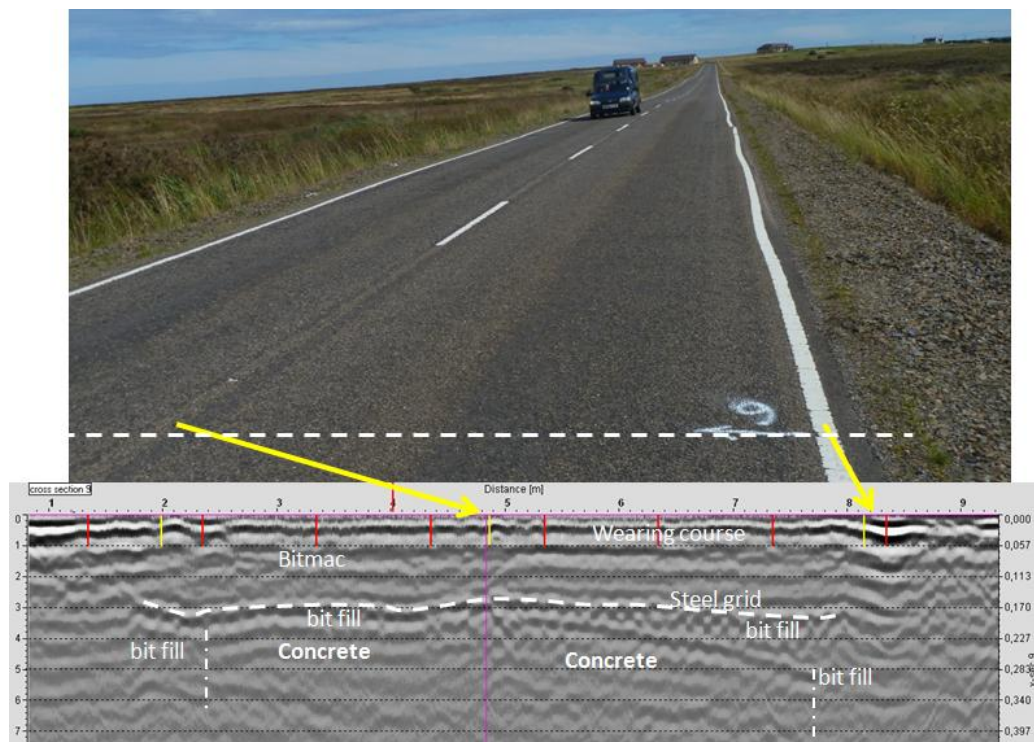


Figure 4.4.1_12. 1.5 Ghz GPR cross section from a well performing road section with no damages. There is 40 – 100 mm of bituminous material between the steel grid and concrete slab. The slab on the right hand side (left lane) has started to tilt. Yellow arrows show the location of road centre and right edge in GPR data

Figure 4.4.1_13 gives an example of longitudinal GPR profiles with FWD deflection bowls from a short section and Figure 4.4.1_14 gives GPR interpretations and FWD deflection bowls from the full road section surveyed. This data confirms that the structure has been performing better on those sections where there are bituminous layers beneath the steel reinforcement. The FWD data

also shows that the biggest problems with load distribution are in the areas where the structure thickness is changing. The total deflections are much higher in the left shoulder that is mainly used by the heavy traffic. Figure 441_14 also verifies that the steel grid should have been installed deeper in the structures, ie at depth of 250 mm as ROADEX recommends. This can be seen in the road section at chainage 200 m where steel grids are at depth of 250 mm and the deflections are “perfect”, confirming the benefit of the high tensile strength of a steel grid when it is optimally used. Installing steel grids deeper was discussed during the design phase but could not be done because of the higher cost of the work, and lack of available funding.

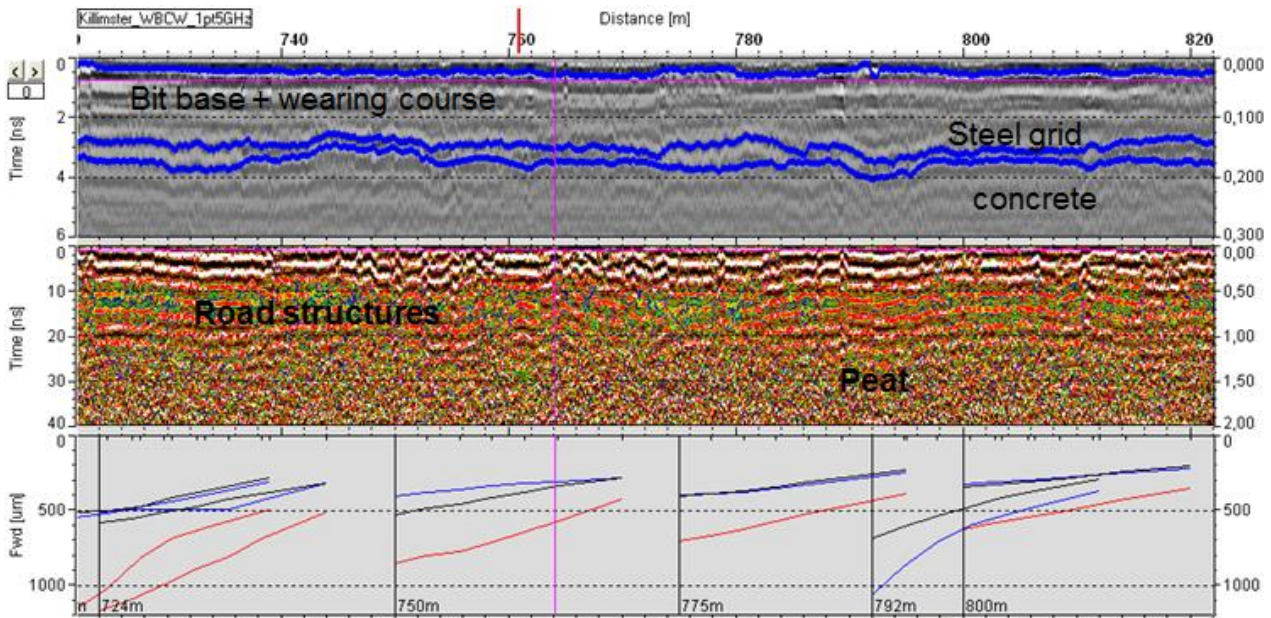


Figure 4.4.1_13. 1.5 GHz GPR data (top field) showing the thickness of the wearing course and bituminous base, steel grid and concrete surface level. The middle field presents 400 Mhz GPR data showing the road structures and underlying peat. The lowest field presents the FWD deflection data. The black FWD deflection bowls are taken from the road centre (concrete), the blue bowls are from the right shoulder and the red deflection bowls from the right shoulder.

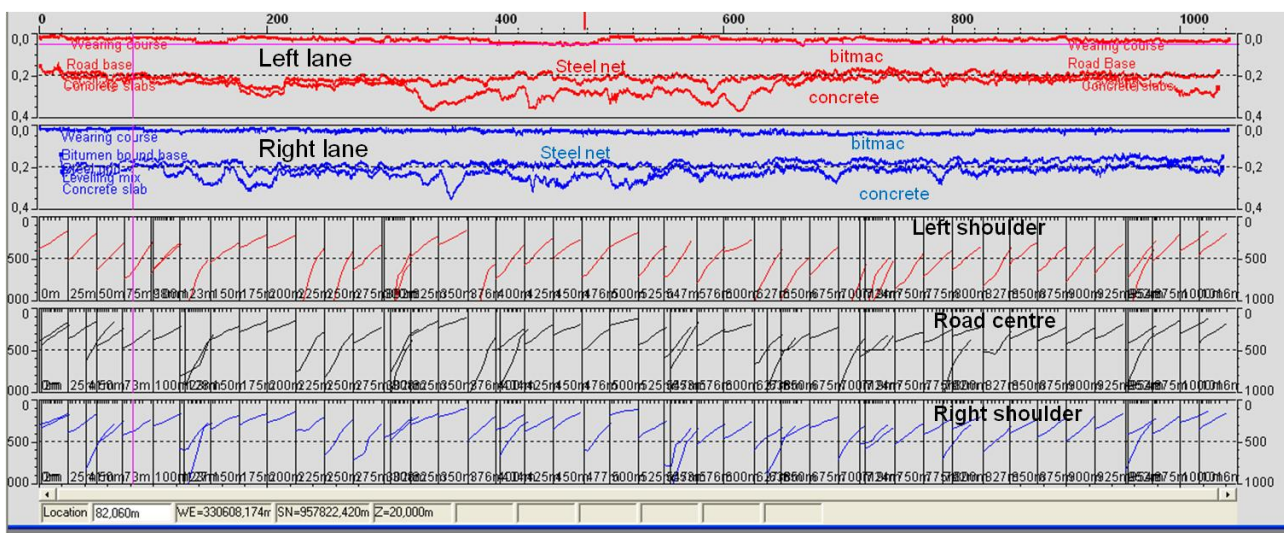


Figure 4.4.1_14. GPR data thickness interpretation (red: left lane, blue right lane) and FWD deflection bowls (red: left shoulder, black: road centre, blue: right shoulder) from Killimster Moss. See “perfect” deflection bowl shapes around 200 m in all survey lines where the steel grid has been installed deeper.

During the design phase the designers of the Highland Council were concerned about longitudinal reflection cracking appearing on the widened area at the edge of the concrete slab. In the event these cracks appeared only in a few places and in that respect the steel reinforcement structure has performed surprisingly well (Figure 4.4.1_15).



Figure 4.4.1_15 Reflection crack at Killimster Moss indicating the edge of the concrete slab.

In summary, in the future in order to avoid similar problems, it should be remembered that at least 50 mm of bituminous layers should be placed on top of the concrete slab to ensure good bonding of the steel grid. The other lesson learned is that steel grids should be installed deeper in the structure so that their tensile strength can be fully be used.

4.4.2. Sibster, road B874

A test section from road B874 was measured in the first ROADEX project in 2000 in order to test how well a geogrid had been performing on a marginally widened weak low volume road resting on peat. The road was originally built in the mid 19th century and Rehau geogrid was installed during a road widening in 1992. According to the Council road data base this single lane road had been given seven layers of surface dressing and thin overlays since the early 1970's. The road was then slightly widened and Rehau grid laid with a 60 mm of bituminous overlay with one more layer of surface dressing given the following year (Figure 4.4.2_1). The ROADEX survey in year 2000 showed that the road shoulders were still settling (Figure 4.4.2_2)

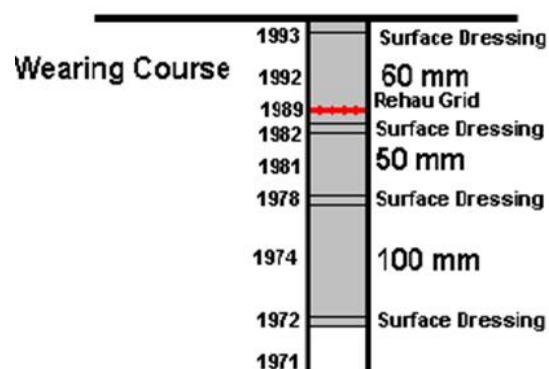


Figure 4.4.2_1 Paving history of the Sibster road from 1970's to the first ROADEX survey in 2000.

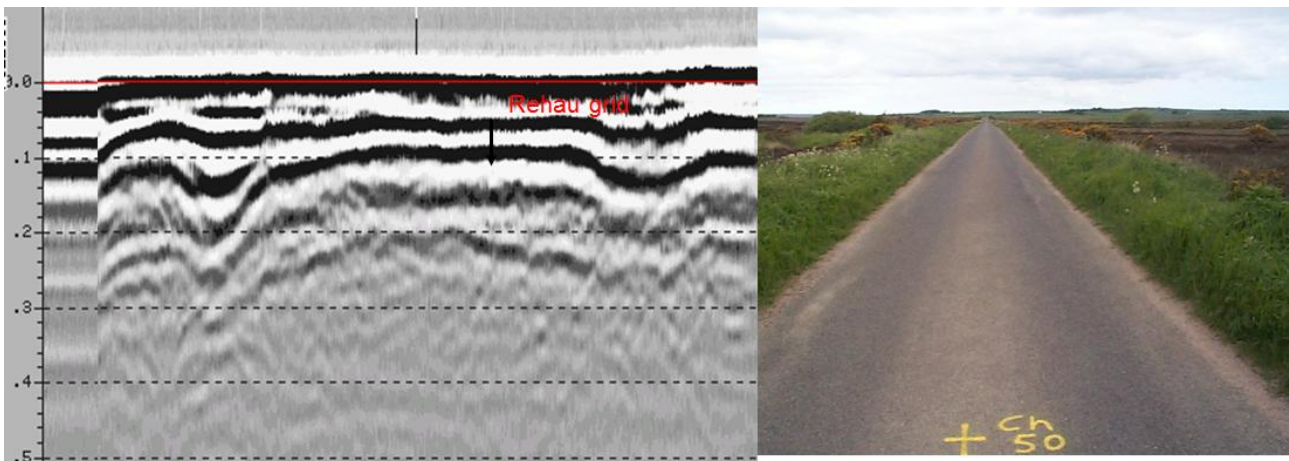


Figure 4.4.2_2 GPR cross section measured in 2000 at the Sibster ROADDEX test section chainage 50 m. GPR data (left) shows about 60-80 mm settlements in the road shoulders and the photograph shows additional settlements since last paving.

The 1.5 GHz GPR cross sections measured in 2011 (Figure 4.4.2_3) showed that a further overlay had been laid on the road since the 2000 surveys. This overlay was slightly (10-20 mm) thinner in the widened road shoulders but visual examination did not show any further settlement in these areas. This means the consolidation of the peat in the widened area is now roughly the same as under the old road and no more differential settlements in the cross sections should be expected.



Figure 4.4.2_3. Photograph from the B874 road together with a GPR cross section measured in 2011. The data shows that the road structures have quite uniform thickness in road cross section. The strong reflections in the upper part of the pavement on both sides of the road show that water is infiltrating into the pavement structure due to the presence of verges.

Figure 4.4.2_4. presents some interesting information about the performance of the Rehau geogrid in the Sibster test section. It shows that geogrid has had shear failures in the sections where there have been differential settlements and where pavement thickness is changing, just like in the Killimster Moss road.

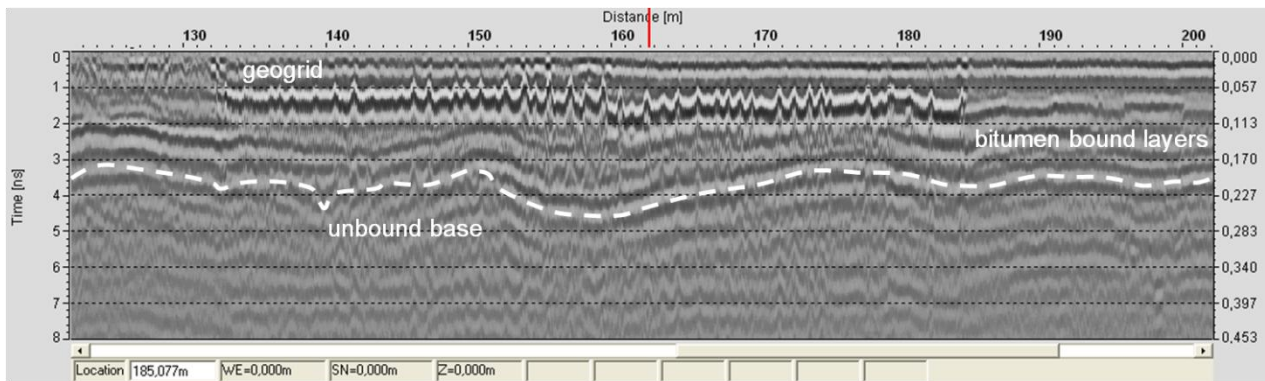


Figure 4.4.2_4. 1.5 GHz GPR longitudinal section of Sibster test site (133 – 184 m) showing the Rehau geogrid in the pavement at the level of 60-90 mm. Cracks in the geogrid can be seen as hyperbolas in the GPR data.

4.4.3. Rogart, road A839

The ROADDEX test section on the A839 road in Rogart was reconstructed and widened from 1960 to 1970. The construction consists of 40 mm of bituminous wearing course over 60 mm of bituminous base course and 200 – 250 mm of unbound base. On the top there are also several layers of surface dressing. The subgrade is glacial moraine. This road section has proved to be a relatively well behaved road widening project with only minor edge damage on the inside of curves with grass verges. Figure 4.4.3_1 gives an example of a GPR cross section and photograph at chainage 50 m measured in 2000. This shows that the layers were quite uniform except in the widening part and that the top part of unbound base and the bound layers close to pavement edge were adsorbing more water.

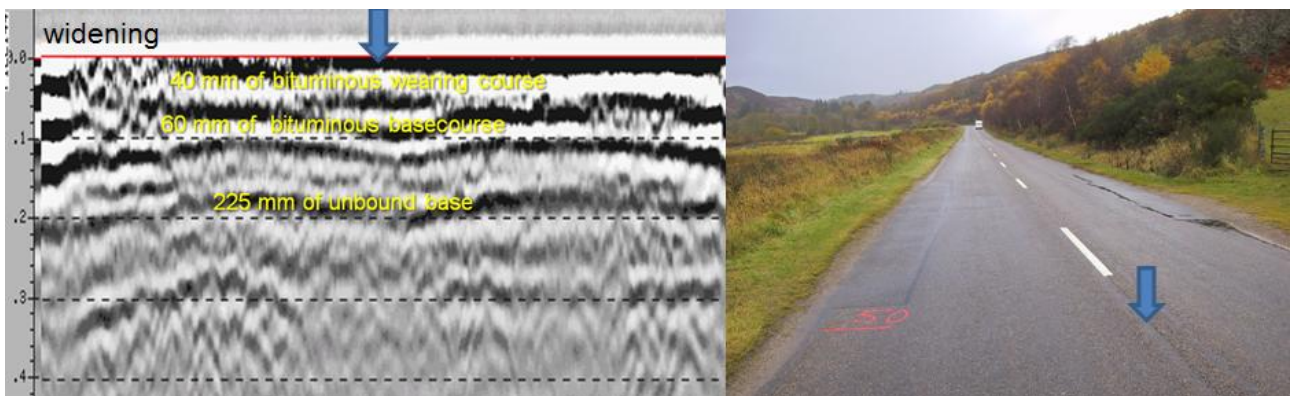


Figure 4.4.3_1. A 1.5 GHz GPR cross section and digital photograph of the Rogart test section measured in 2000. Strong reflections in the bound layers and the top part of the unbound base in the widened area in left indicate high amount of moisture in the structure.

Figure 4.4.3_2 presents a typical GPR cross section measured in Rogart in 2011. It shows that the road has had an overlay of approximately 30 mm thick on the top of old pavement in the last ten years. The cross section also shows that the thickness of the overlay is slightly thicker in the left edge of the pavement indicating that the compaction of the widening might not have been sufficient enough and that there has been small amount of Mode 0 rutting in the widened area due to compaction. This phenomenon could be seen in all the surveyed cross sections. The Rogart test section has drainage deficiencies in the left side of the road as the GPR data shows strong reflections indicating high moisture content in the pavement.

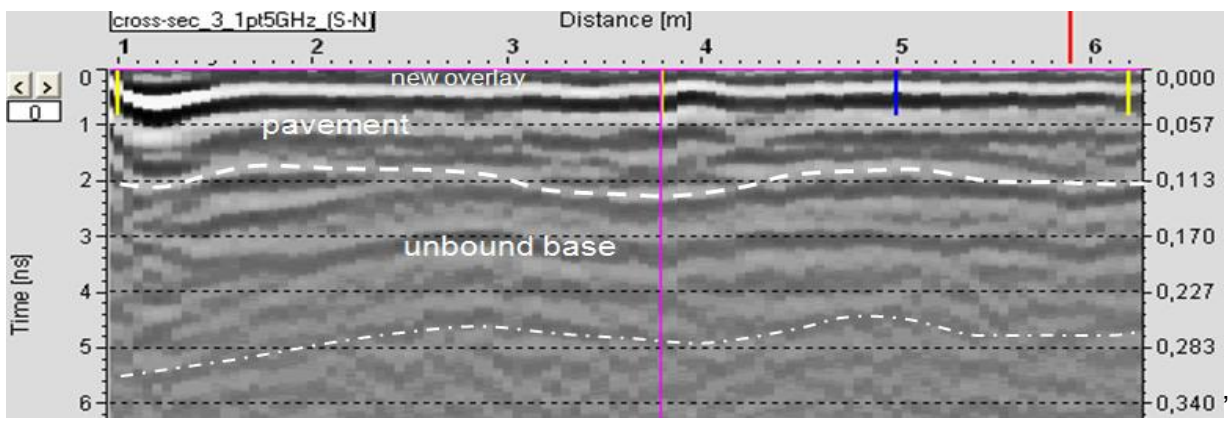


Figure 4.4.3_2. Example of a 1.5 GHz GPR cross section on the Rogart test section in 2011.

5. SUMMARY AND CONCLUSIONS

The selected ROADEX IV road widening test sections provided a good overview of the different types of problems that can result from the design and construction of road widening project. A short summary with conclusions and recommendations is provided in the following.

The “light widening” structure on Hw 9 in Finland has been working very well for the first two years after construction. The road has maintained its cross section profile shape; there are no pavement damages resulting from the widening structure, and no temperature anomalies either. No indications of rapid development of damages were noted during the two year follow-up period. On the other hand, unlike Hw 9 in Finland, the light widening structure on the Ohtanajärvi road in Sweden has not been working well and road has badly failed. That is because the old road was too weak at the beginning, and should have been strengthened during the widening. Spring thaw weakening and Mode 2 rutting has caused the soft subgrade soil to flow from beneath the road to both sides. This has lead to deformations and “unwanted widening” of the road by itself, and this widening is still going on. Thicker structures and steel reinforcement might be a solution for the problems in Ohtanajärvi.

The results from road 75 in Finland showed that even though the road has been widened, the widening structure is not always the biggest reason for the road damages seen. Not many of the damages on the road could be clearly related to the widening. However the road was distressed badly with alligator cracking on the wheel paths. There were also many patched sections and some shoulder deformation. These damages showed clear indications of pavement fatigue and bearing capacity problems due to a road structure that was too thin, and to drainage problems. Drainage problems with private access road culverts blocking the water flow might have triggered the failures on the widened side.

The Salmi test section in Sweden gave an example of a road with higher quality rehabilitation and widening. The road structure is strong and generally the road has been working very well, although there have been some reflection cracking. One clear construction error that causes reflection cracks was found on this test section, when it was surveyed the first time some ten years ago. An old bituminous pavement layer had been left inside the structure during the upgrading and widening of the road. As a consequence, a reflection crack occurred on the road surface where the pavement edge ended and the new widened part began. This so called “sandwich structure” must be avoided when designing a widening or any other kind of road rehabilitation.

On the widened Karrbäck road in Sweden there were some settlement and severe rutting taking place on the widening side, but the main problem with that road was not related to the widening. The whole road is settling into the extremely soft silty subgrade. This phenomenon is made even worse by the fact that the ditches are filled, which causes the drainage to be ineffective.

The steel reinforcement structure on Lapträsk road in Sweden was performing quite well, and there should not be any problems on this site in the near future. The results from this road showed, that the use of steel nets in road widening is always a recommendable solution. However it is essential that the reinforcement is installed deep enough inside the structure.

Good experiences on the use of steel reinforcement were also obtained from the Killimster Moss road in Scottish Highland. The lessons learned from the failed sections, after 10 years of service life, is that the steel grid should not be installed directly on top of the concrete slab and that there should be at least 30-50 mm bound layers beneath the steel grid. Also FWD data showed clearly that steel grids were performing optimally only on those section where there were at least 200 mm thick layers on the top of the grid.

The results from the Engerud road in Norway showed the glassfibre strengthening had not been able to prevent the reflection cracking taking place. It can be concluded from this that that glassfibre is not an adequate strengthening method, if there are vertical shear forces due to frost

action taking place in the widening joint. The geogrid test data from Sibster in Scotland gave similar results but the reason there was differential settlements, and a high variable deflection behaviour over a road resting on peat.

The test results in the old ROADDEX test sections resting on peat (Kjosenmyra in Norway and Sibster in Scotland) showed major improvement in the road condition over the last ten years. This can be explained by the fact that the greatest part of peat consolidation beneath the widened area had now taken place and that the peat stiffness was on the same level in the road centre and on the widened area. In this case no major settlement should take place anymore. So one solution in such cases is "time", i.e. continue to patch and wait until there settlement stops.

The Rogart test section has been still performing well since the last inventory 10 years ago. The only small problems were minor settlement in the widened area indication inadequate compaction during the widening construction, and the presence of roadside verges trapping surface water on the road.

APPENDIX: SUMMARY OF THE LITERATURE REVIEW AND THE QUESTIONNAIRE RESPONSES

This appendix provides a summary of the results of the review and comparison of current national guidelines, and the questionnaire on road widening. The results are examined and discussed in greater detail in the earlier report *“Road Widening: literature review and questionnaire responses”*.

NATIONAL GUIDELINES

Scope

There are a number of differences between the nationally agreed guidelines on road widening across the ROADEX countries. Some of the countries have own guidelines and some have not. Widening instructions for existing road are partly similar but there are also some differences as designing and construction can be carried out in many ways. The main difference in road widening guidelines across the ROADEX countries is in the scope of information provided. Some guidelines include detailed drawings and phased instructions for road widening for various circumstances. Other guidelines merely offer general advice on possible alternatives, for example using a geogrid or steel grid. Some countries have not published widening instructions. In some, road widening guidelines are given in one separate publication, while in other countries the guidelines are parts of many different manuals. There are also references to other countries' manuals in some guidelines.

The Finnish Road Administration's guideline provides extensive guidance for road widening in different circumstances. The widening guidance is given in one dedicated chapter in a design guideline. The road widening guideline of the Iceland Road Administration provides a good general knowledge of road widening. The Design Manual for Roads and Bridges (UK) is an extensive publication, but the guidance on road widening is slight. In Norway, guidance on road widening is given in a range of handbooks. A dedicated guideline was not identified. Nationally agreed guidelines were not identified for Greenland, Ireland and Sweden.

Required surveys

Road widening guidance in Finland recommends using information from the national database on road structure, old design documents and interviews. Any information from these sources should however be verified for example by excavation, test pits and drill cores. It is essential that the thickness of structure layers and subgrade reinforcement are surveyed. It is also important to find out frost susceptible areas, large shoulder deformation areas, stiff and thick bound layers and the need for reinforcement. If the road has been previously strengthened or widened it is also important to survey the types of structures within the existing road. The Finnish guidance also states that sometimes it will be necessary to carry out the road reconstruction without a survey of the existing road if the costs of the survey are very high. This could arise when the repairing method has already decided and is not dependant on the underlying reasons for the existing failures. In these cases one should be prepared to review work practices during the reconstruction in the light of conditions found.

The road widening guide in Scotland recommends carrying out a full assessment of the condition of the existing pavement ahead of the widening work. 'As-constructed' records are also recommended as providing a useful source of information. It is however important to verify the accuracy of any historic records with exploratory excavation. The guidelines contain separate guidance on the analyses of pavement surveys, the interpretation of results, and the design of appropriate strengthening measures.

The road widening guides in Norway do not provide detailed advice on the types of surveys to be carried out before widening. The Icelandic guideline includes advice on surveys. It recommends that the condition and materials of the existing road should be surveyed. Survey methods recommended include sampling, grading analysis and CBR measuring using DCP. It is considered that careful surveys will make it easier to ensure the similarity of widening structure and evaluate the need for reinforcement.

All the national guidelines are relatively old and there are no references to the latest technologies that can be used in widening projects.

Construction joint

One difference between the instructions of the ROADDEX countries is the shape of the construction joint. The guidance in Finland, Iceland and Norway recommends excavating the embankment using an angled cut while the DMRB of Scotland advises the use of a stepped joint. The Finnish guideline recommends an angle from 4:1 to 2:1. The Icelandic rule is that if the side slope of the ground is steeper than 1:6 the excavation should be cut at an angle of 1:1.25 or steeper. The Norwegian guide additionally recommends that the shoulder of the existing embankment should be cut at angle of 1:2.

Joint location and widening on both sides

The Finnish guideline states that the joint between the new and old construction should not be located under the wheel path and that the joint of the bound layers should not be located in the same place as other joints. The guidance also recommends that the existing pavement should be cut 0.3 m – 0.5 m in from the embankment joint. The corresponding advice from the Scottish DMRB is that the joint should be placed mid lane, or near the lane dividing line, in order to avoid wheel tracks. Short lengths of joint crossing a lane diagonally, such as in realignment, may be acceptable. The Icelandic guide also recommends that placing the construction joint under wheel path should be avoided if possible. The Norwegian handbooks do not give guidance on this issue.

Usually the guidelines recommend that widening should be carried out only to one side of the road as this reduces costs. The Finnish guideline also gives some advantages to widening both sides of a road. When widening both sides of the road, construction joint cracking and non-uniform settlement normally develops in the shoulders, and not in the loaded part of the road. Similarly, the need for soil reinforcement or additional land can be lessened and deformation can be expected to be smaller. The Icelandic guideline also permits widening on both sides in some situations. Norwegian guidelines recommend that widening should only be carried out on one side of the road. The Scottish guideline mentions both widening methods.

Old drainage structures

It is normally acceptable to leave the old drainage structures in widened carriageways in Finland although paved channels are required to be removed in motorways or other high traffic volume roads. Drainage channels should not be located in wheel tracks. In the Scottish guideline it is normally unacceptable for manholes and channels to be located on high speed carriageways. The Norwegian and Icelandic guidelines do not offer any recommendations on old drainage structures.

Costs

The Finnish guide does not include much information on the estimation of costs, only general comments on the need to avoid excess costs. The Finnish Road Administration publication dealing with the use of steel grids states that investment costs should be an essential consideration in estimating the profitability of a road project. It recommends that life cycle costs should be

considered during the project planning stage. This can be difficult however where the initial data is poor and can result in the analysis being unreliable. It is useful however to consider the whole life costs of widening measures as some, such as using steel grids, can clearly prolong the period of operation and decrease the need for maintenance.

The UK guideline recommends that all options for carrying out the works should be assessed on the basis of minimising whole life costs over a 40-year analysis period. The Manual also recommends that consideration should be given to the principles of sustainable development and the future maintenance costs of the existing and widened elements of the pavement. Where site constraints or operational procedures require a solution other than that which would give the lowest whole life cost, approval must be sought from the Overseeing Organization, supported by evidence to demonstrate that the proposed solution will provide acceptable value for money.

Norwegian and Icelandic guidelines do not contain much information on the estimation of cost. The main point mentioned is that cost estimating is difficult and case-specific.

THE ROADEX QUESTIONNAIRE ON ROAD WIDENING

A main purpose of the ROADEX road widening report was to study road widening practices in the ROADEX countries. A road widening questionnaire was made and sent to experts in the ROADEX countries in order to collect their experiences and knowledge of local practices in road widening. The responses for the questionnaire are summarized in the following chapters.

Topography and geometry

The existing road topography and geometry were considered to pose occasional problems for road widening projects. The lack of space was also mentioned to be a problem by some, depending on their areas. For example, creating more space by felling trees adjacent to low-volume forest roads was not a problem. Respondents reported that local landowners were normally helpful in allowing road works to proceed as long as land encroachment was kept to a minimum. Where space was limited, respondents had used steeper side slopes with reinforcement and/or retaining walls. The choice of the most suitable type of drainage system was a consideration for sites with space problems. Diagonal construction joints between the old and the new structures were reported as presenting problems, especially where the new road involved improvements to sharp curves on existing roads.

Construction and repairing techniques

When making a construction joint between the existing road and the new widening, the commonly recommended method is to construct equal structures in the old and new parts of the embankment. The joint construction type will depend on the formation type and the subgrade soil. A stepped joint and an angled joint are both commonly in use in the ROADEX areas, and a vertical joint is also sometimes used. Many of the respondents did not recommend any particular angle, but some suggested angles between 45° to 80°. Many recommended that the pavement layers should be cut or staggered in some way. The use of geotextile or steel grids was recommended under new paving, under the base course and under the sub-base. The wrapping of unbound materials in a geotextile was also recommended. These types of reinforcement must be firmly tied into the old embankment. Gabions and reinforced earth were also reported as being used. One solution used the existing embankment as a uniform base layer for the new road. Lack of compaction of filling materials was considered to result in lateral movement in the widened area. This was a commonly observed phenomenon.

Most of the respondents recommended that construction joints should not be located under the wheel path. In some Partner areas the joint location is determined just by the width of existing

embankment and the widening. Methods for minimising reflection cracking over the joint included constructing an equal structure in the widened portion, allowing sufficient time for settlement before overlaying, the use of a stepped joint between the pavement layers, and ensuring sufficient lateral transverse support.

Most of the respondents recommended that it was necessary to find out the reasons for the failures before carrying out the repair of a widened road. This involved understanding the initial situation and analysing the reasons underlying the failure. In some cases the widening has had to be reconstructed. Sometimes the use of a steel grid has been enough.

Surveys

The structural layers of the existing road and embankment must be carefully researched before widening is carried out. The most common way of doing this according to the replies received were by excavating test pits, ground penetrating radar, referring to old design documents and taking drill cores. Some of the respondents stated that they only excavated test pits. It was considered that any existing reinforcement in the road should be identified before widening and that the road should be monitored and topped up during the settlement period. Some of the reported failures had happened as a result of a poor evaluation of the original embankment and subgrade. The actual thickness of layers and materials were sometimes only discovered during the excavation of the existing embankment.

Settlement and peat soils

It was considered that the old embankment and the new structure should settle similarly. When asked how to prevent cracking between the old and new part of embankment due to uneven traffic loading respondents gave a number of replies including the use of preloading and reinforced structures. The use of site transport to compact the widening was also mentioned. It was felt that the final paving should be laid after the traffic had loaded and compacted the widening. This was stated to reduce lateral settlement. A temporary pavement was recommended during settlement period. Some respondents reported that projects had not been given adequate time for settlement before paving. These had consequently had failures in the new pavement.

Road widening on peat soils was regarded as a major problem. It was again considered essential that a uniform settlement was achieved across the old and the new part of the embankment. Assessing the settlement of the existing embankment was reported to be difficult as it usually had already settled due to the weight of the structure and the traffic load. Settlement in the existing embankment could be restarted or increased after adding the widening section, or during upgrading the road. It was also considered difficult to evaluate the settlement of the new part of the road.

The most common methods of dealing with widening on peat soils were using overload embankments, geogrids, steel reinforcement, and soil replacement down to a hard base. Piles, stabilization, lightweight structures, timber stumps and logs had also been used. The most commonly agreed method was to construct the layers of the widening equal to those of the existing embankment, and to have them tied to it with reinforcement such as geogrids or steel grids. In areas of deep soft ground it was considered important to separate the new construction layers from the subgrade. This was commonly carried out by using a separating fabric to prevent the migration of materials, leading to settlement.

Drainage

Drainage was generally considered to be a minor problem in road widening as the new drainage system was usually better after the widening works, particularly if enough space was available. A

range of steel and plastic culverts, pipes and open channels had been used in drainage systems. One respondent recommended all the sub drains should be replaced during road widening as the joints between the old and new pipes could loosen. All agreed that the drainage system should be continuous from the old to the new, and that any discontinuities should be avoided. Poor drainage systems were reported as causing edge failures and weakening the road structure. The surface shape of the ground had to be considered in the design of the drainage system as it could restrict its efficiency. It was felt that a good drainage system was dependant on the subgrade and the formation of the road. The available space at the side of the road had a great effect on the type of drainage system that could be chosen.

Frost action

The recommended methods to minimise frost action included insulation, good consistent drainage, geotextiles, reinforcement and building similar structures to the widening side. Often the old road was improved at the same time as the widening, e.g. by adding aggregate. This practice was considered to decrease the impact of frost thaw and the risk of failures. Where pavements were broken, surface water had entered and had been absorbed into the embankment. Possible repair solutions for frost damages included installing geogrids and steel grids. One possible way of minimising damage to low volume roads during frost susceptible periods was to control the traffic loading.

Slope stability

When asked about the steepening of side slopes on road widenings due to lack of space, respondents reported some slippages. These had happened in the spring when the moraine slopes had flowed. A number of methods were given to improve slope stability; using a geotextile, heavy rip-rap to support the slope, retaining walls and stepped batters were considered to be feasible alternatives. Vegetation on the slopes was usually the most economical way to reduce local erosion on the slopes. A workable drainage was also considered necessary to assure stability. On low-volume forest roads it was often easier to create more space for gentle slopes by felling more trees.

Bedrock

The cost of widening of roads constructed close to bedrock was considered to be a significant issue. Some respondents mentioned that they had had problems estimating the costs and rock masses involved. If there were no other constraints, the bedrock was usually blasted and excavated, with the resulting rock material used for construction depending on the quality of aggregate produced. Transition wedges were considered necessary where the bedrock was below the road. The variable surface of bedrock was stated to pose non-uniform settlements and frost effects if not dealt with. Surface water runoff had to be monitored to ensure that it worked and this could require surface reshaping. Drainage arrangements in shallow construction were a particular problem that had to be planned in order to keep the low water table low within the road. Sometimes the width of side drain had been reduced to ease the cutting of bedrock. Rock netting was recommended for unstable cliffs.

Traffic Management

All respondents reported that their arrangements for traffic management depended on the speed and traffic volume of the road. Some forest roads had been closed during widening works. On high traffic volume roads traffic management had to be planned more carefully and it was recommended that this should be part of the contract. Normally at least one lane was kept open for traffic during construction. The widening works and the order that the works were carried out, had to be carefully planned, and adequate resources given, to ensure that the working period could be

minimised. The timing of works was also considered critical in order to avoid rush hours. Well carried out surveys could prevent delays, as could the use of bypasses and temporary widenings.

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.