

Eesti põhimaanteeede kvaliteedi hindamise ekspertuuring

Road construction quality surveys with
non-destructive methods on selected sites in Estonia



Eesti põhimaanteedde kvaliteedi hindamise ekspertuuring

Road construction quality surveys with
non-destructive methods on selected sites in Estonia

Annele Matintupa, Tomi Herronen, Anssi Hiekkalahti and Timo Saarenketo

2012

Preface

This report “Eesti põhimaanteed kvaliteedi hindamise ekspertuur, Road construction quality surveys using GPR method on selected sites in Estonia” was ordered by the National Audit Office of Estonia (Riigikontroll). The main purpose was to find out with non-destructive methods if the road construction and condition meet the design documents. The project was carried out in August – November 2012.

The field measurements were performed by Tuukka Saikka and Anssi Hiekkalahti. Processing and analysis of the measured data and writing of report was carried out by Annele Matintupa, Tomi Herronen and Anssi Hiekkalahti. Tomi Herronen was responsible for operative functionality and Timo Saarenketo participated as general expert on roads, their condition and behavior.

Some of the background information is based on ROADEX-research projects. The ROADEX Project is a technical co-operation project between roads organizations across northern Europe that aims to share information and research related to roads between the partners. Further information of ROADEX project can be found at their website www.roadex.org.

Project team would like to thank Jaanus Saadve, Jaanus Kasendi and Margit Grauen from Riigikontroll for the help to finish this report.

Contents

PREFACE.....	2
CONTENTS.....	3
1. INTRODUCTION.....	6
2. ROADS SURVEYED.....	8
3. DATA COLLECTION	9
3.1 GPR – GROUND PENETRATING RADAR	9
3.2 VIDEO AND GPS.....	11
3.3 LASER SCANNER	11
3.4 ACCELEROMETER.....	12
3.5 SAMPLING	13
4. PROCESSING, INTERPRETATION AND ANALYSIS.....	15
4.1 GPR DATA	15
4.2 LASER SCANNER DATA	16
4.3 ACCELEROMETER DATA.....	17
4.4 DRAINAGE EVALUATION	18
4.5 SAMPLING	18
4.6 OTHER.....	19
5. COMPARISON OF STANDARDS IN ESTONIA AND SOME OF THE NORDIC COUNTRIES	20
5.1 DESIGN IN GENERAL.....	20
5.2 ROAD STRENGTHENING DESIGN, FINNISH PRINCIPLES	20
5.3 ROAD STRENGTHENING DESIGN, SWEDISH PRINCIPLES AND PRACTICES	22
5.4 COMPARISONS WITH ESTONIAN PRACTICES	24
5.5 ROAD PERFORMANCE SPECIFICATION.....	28
5.5.1 Rutting performance.....	28
5.5.2 Roughness performance	29
5.6 ROAD DESIGN COMPARISONS.....	30
5.6.1 General.....	30
5.6.2 Bound Layers.....	31
5.6.3 Other Road Structure.....	31
5.6.4 Bearing Capacity.....	32
5.6.5 Conclusions	32
6. RESULTS	33
6.1 SECTION 1 – ROAD 1 KM 64-67	33
6.1.1 Designed Structure	33
6.1.2 GPR	34
6.1.3 Laser Scanner.....	35
6.1.4 Accelerometer.....	36
6.1.5 Rutting	36
6.2 SECTION 2 – ROAD 1 KM 22-25	37

6.2.1 Designed Structure	38
6.2.2 GPR.....	38
6.2.3 Laser Scanner.....	38
6.2.4 Accelerometer.....	39
6.2.5 Rutting	40
6.3 SECTION 3 – ROAD 1 KM 42 - 45.....	41
6.3.1 Designed Structure	41
6.3.2 GPR.....	42
6.3.3 Laser Scanner.....	42
6.3.4 Accelerometer.....	42
6.3.5 Rutting	44
6.4 SECTION 4 – ROAD 3 KM 82-85	45
6.4.1 Designed Structure	45
6.4.2 GPR.....	46
6.4.3 Laser Scanner.....	47
6.4.4 Accelerometer.....	49
6.4.5 Rutting	50
6.5 SECTION 5 – ROAD 3 KM 198-201	50
6.5.1 Designed Structure	51
6.5.2 GPR.....	51
6.5.3 Laser Scanner.....	51
6.5.4 Accelerometer.....	52
6.5.5 Rutting	54
6.6 SECTION 6 – ROAD 2 KM 150-153	55
6.6.1 Designed Structure	55
6.6.2 GPR.....	55
6.6.3 Laser Scanner.....	57
6.6.4 Accelerometer.....	59
6.6.5 Rutting	60
6.7 SECTION 7 – ROAD 4 KM 58-61	61
6.7.1 Designed Structure	62
6.7.2 GPR.....	62
6.7.3 Laser Scanner.....	63
6.7.4 Accelerometer.....	63
6.7.5 Rutting	65
6.8 SECTION 8 – ROAD 4 KM 144-147	66
6.8.1 Designed Structure	66
6.8.2 GPR.....	66
6.8.3 Laser Scanner.....	67
6.8.4 Accelerometer.....	68
6.8.5 Rutting	69
6.9 SECTION 9 – ROAD 4 KM 130,8-133,8	70
6.9.1 Design Structure.....	71
6.9.2 GPR.....	72
6.9.3 Laser Scanner.....	74
6.9.4 Accelerometer.....	74

6.9.5 Rutting	75
6.10 SECTION 10 – ROAD 9 KM 58-61	76
6.10.1 Designed Structure	77
6.10.2 GPR	78
6.10.3 Laser Scanner	79
6.10.4 Accelerometer	79
6.10.5 Rutting	80
7. SUMMARY OF THE RESULTS	82
7.1 GPR	82
7.2 RUTTING	82
7.3 ROUGHNESS	83
7.4 BEARING CAPACITY ANALYSIS	84
7.5 TRANSVERSE CRACKS	84
7.6 ROAD WIDTHS	85
7.7 STATISTICS OF RUTTING AND ROUGHNESS	85
8. SUMMARY AND CONCLUSIONS.....	88
DESIGN	88
CONSTRUCTION.....	90
MAINTENANCE.....	90
APPENDICES	91

1. Introduction

Roadscanners performed a detailed survey in summer 2012 on ten selected main road sections rehabilitated during the last ten years in Estonia. The primary goal for this project was to check if the road were constructed according to the design documents and what was the current road condition and remaining life time after the construction. Another goal was compare the Estonian road design norms and guidelines with corresponding guidelines in Finland and Sweden. The project was ordered by National Audit Office of Estonia (Riigikontroll).

The survey methods used in this project were ground penetrating radar (GPR, for the thicknesses of road structures), digital video (to evaluate the current road condition) and GPS positioning, accelerometer (for road roughness) and laser scanner (to detect road crossfall and slopes as well as ditches and approximate road width). Rutting was also evaluated from laser scanner data. The interpreted layer thicknesses were compared to the designed structures. Also profilometer data and bearing capacity data from Estonian road data base were analysed.

This report presents the results of an integrated analysis of the results of all the aforementioned survey methods. As a remark, one difference in terminology used in Finland and Estonia should be mentioned here. The term “stabilisation” has been used in many chapters of this report. In this report “stabilisation” means extra bituminous base material that has been built on the top of old pavement.

In report has been referred to ROADDEX projects and rutting modes that have been defined in context with the project. Figure 1_1 presents short description of each mode. The formation of **Mode 0** rutting is due compaction of road structure. **Mode 1** rutting happens in weaker granular materials where local shear occurs close to the wheel. This gives rise to dilative heave immediately adjacent to the wheel track where the granular material can undergo large plastic shear strains and consequent dilation, leading to relatively loose material. **Mode 2** rutting occurs mainly over weak subgrade soils where the pavement structure as a whole ruts. The **Mode 3** ruts are developed due to tire wear of the pavement of a paved road, or the wearing course of a gravel road.

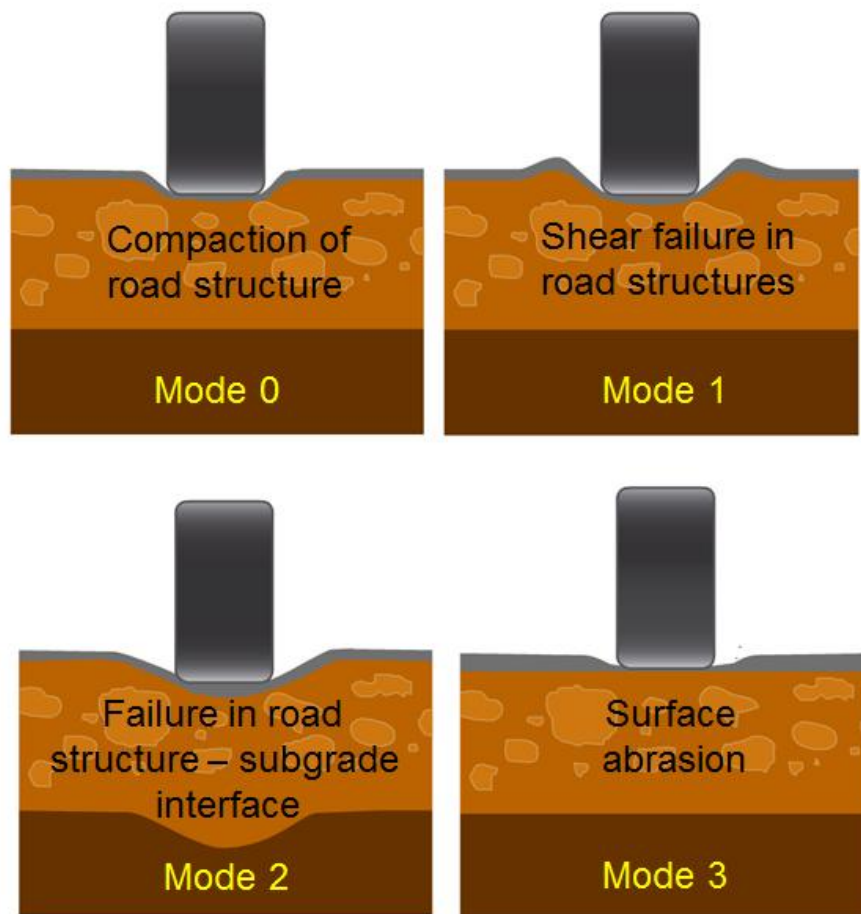


Figure 1_1. Principles of different rutting modes.

2. Roads Surveyed

In this project 10 sites were surveyed, the length of each site was 3km and the sites were selected by Riigikontroll. The road sections are presented in a map in Figure 2_1 and detailed information of them is presented in Table 2_1.

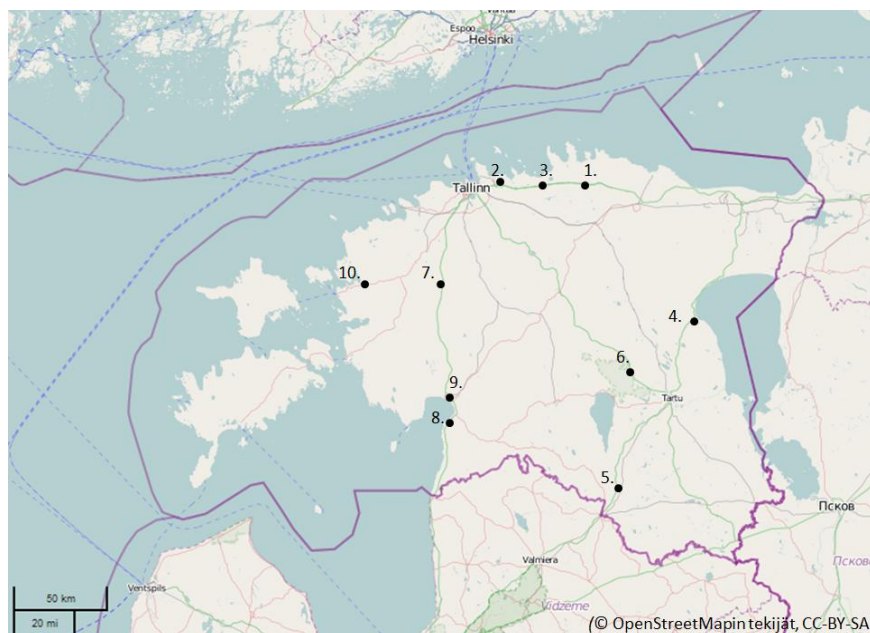


Figure 2_1. The surveyed road sections presented on a map.

Table 2_1. The measured road sections with detailed information.

Jrk nr	Tee nr	Maantee ja renoveeritud lõigu nimetus	projekti läbiviimise aasta	Uuringu 3-km lõik	kontroll-lõigu lähiaadressid
1	1	Tallinn-Narva: Liiapeksi-Loobu	2009-2011	64-67	Valgejõe-Läsna
2	1	Tallinn-Narva: Maardu- Valgejõe	2005-2006	22-25	Maardu-Kodasoo
3				42-45	Kuusalu-Vahastu
4	3	Jõhvi-Tartu-Valga: Raja-Kääpa	2005-2007	82-85	Metsaküla-Ruskavere
5	3	Jõhvi-Tartu-Valga, Ametmäe-Valga		198-201	Rõngu-Jaanikese
6	2	Tln-Tartu-Võru-Luhamaa	2002	150-153	Puurmani-Kärevere
7	4	Tallinn-Pärnu-Ikla	2001-2002	58-61	Vaimõisa-Konuvere
8	4	Tallinn-Pärnu-Ikla		144-147	Uulu-Luuri
9	4	Tallinn-Pärnu-Ikla: Papiniidu pikendus	2010-2011	130,8-133,8	Papiniidu pikendus
10	9	Ääsmäe-Haapsalu-Rohuküla: Palivere-Rannaküla	2008	58-61	Pälli-Taebla

3. Data Collection

Data collection was performed in the beginning of August. A short description of each method is given in the following.

3.1 GPR – Ground Penetrating Radar

The ground penetrating radar antenna transmits a short electromagnetic pulse of radio frequency into the medium. When the transmitted wave reaches an electric interface, part of the energy is reflected back while the rest continues its course beyond the interface. The radar system will then measure the time elapsed between wave transmission and reflection. This is repeated at short intervals while the antenna is in motion and the output signal (scan) is displayed consecutively in order to produce a continuous profile of the electric interfaces in the medium (Figure 31_1). The profile is shown in grey or color scale, where different shades or colors equal different magnitudes of the reflected amplitudes.

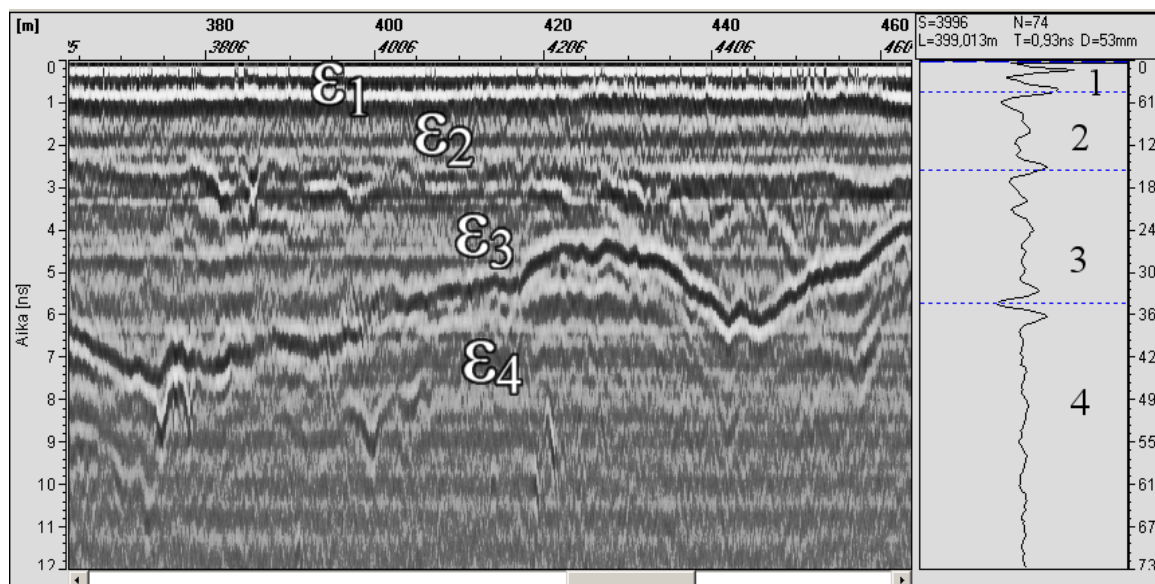


Figure 31_1. Ground penetrating radar profile, measured with an air coupled antenna and its individual pulse. The profile has reflections from interfaces of two mediums with different dielectric properties (ϵ). Image structure's layer 1 describes the pavement; layer 2 describes base course, layer 3 sub-base and layer 4 filtering course. The figure shows that the dielectric value of materials (moisture) increases proceeding downwards from the road surface with the exception of the dielectric value of the filter course (ϵ_4), which is less than that of the sub-base and, as such, the polarity of the reflection is inverted (black line in the middle of two white lines).

In general, the propagation speed of the wave and its reflection are affected by the dielectric value, the magnetic susceptibility and electrical conductivity of the medium. They display variability according to aggregate type used in the asphalt, type of binding material (bitumen) and presence of conductive minerals, presence of porosity and fractures, and finally the effect of salt and accumulation of material in the fillings

of the pores and fractures. The most important electrical property affecting the GPR signal is dielectric permittivity, which affects the GPR signal velocity in the material.

The antenna wavelength affects the ability of the system to identify objects of different sizes. For example, high frequency antennas with short wavelength have better resolution, but shallow penetration depth, while low frequency antennas with longer wavelength have a coarser resolution, but penetrate deeper into the medium.

The air-launched systems operate around 1-2 GHz. The penetration depth of the horn antennas is limited to approximately 1 m. During the data collection antennas are suspended approximately 0.3-0.5 m above the measured surface. The speed of the measurements is high, even up to 90 km/h. The ground coupled antenna used in this survey operates at 400 MHz. Expected depth penetration is about 3 m. Due to the need to maintain a close proximity to the surface, the antenna requires lower survey speed, in this case approximately 40-50 km/h.

Ground penetrating radar (GPR) data was collected using a GSSI SIR-20 unit with two antennas, 1 GHz air-coupled and 400 MHz ground-coupled antennas (Figure 31_2). A digital video with GPS coordinates was also taken.

The survey consists of 6 lines over the road width (right and left wheelpath and lane centre), except on road 1 (sections 1-3) where the measurements were performed only in direction 1 and 5 lines were measured (service lane, right and left wheelpath on both lanes). Cross section GPR profiles were measured on kilometre poles (Figure 31_3).



Figure 31_2. The Roadscanners GPR survey system equipped with a 1 GHz air-coupled horn antenna and 400 MHz ground coupled antenna in the front of the vehicle. A video camera is mounted on the roof top with laser scanner.



Figure 31_3. The cross-sections were measured with SIR-3000 GPR-equipment.

3.2 Video and GPS

The CamLink video-logging system was installed on the van roof. The GPS device model used for positioning was an APD Communications INCA 2. All of the data was linked to GPS using Road Doctor™ CamLink software. One video camera in a CamLink box was used in the survey, to record the view of the road and record pavement distress.

3.3 Laser Scanner

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

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

A laser scanner is composed of three parts, the laser canon, a scanner and a detector. The laser canon produces the laser beam, the scanner circulates the laser beam, and the detector measures the reflected signal and defines the distance to the target. The distance measurement is based on the travel time of light, or phase shift, or a combination of both. The quality and price of mobile laser scanner survey systems vary but they can be roughly classified into two categories a) highly effective

high accuracy systems and b) cheaper, simplified “everyman’s” laser scanner systems that have reduced distance measurement capability and accuracy.

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

In this project the data collection was carried out using a SICK LMS151 laser scanner (Figure 33_1). The laser scanner was mounted to the back of the survey van (seen in Figure 31_2).



Figure 33_1. The SICK LMS151 laser scanner in close-up.

The data analysis was carried out with the new Road Doctor™ Laser Scanner (RDLS) module of Road Doctor™ software. This module facilitates integrated analysis of the laser scanner data and other road survey data.

3.4 Accelerometer

Accelerometer is a device that measures acceleration forces (Figure 34_1). Acceleration is the second derivative of position. When a car drives over a road with roughness, the roughness produces accelerations to the car tire. Bigger amplitude and shorter wavelength of the roughness produces larger acceleration. In other words, severe road damage produces large accelerations. Together with the GPS-positioning system the measured accelerations can be positioned on the road. The

accelerations also depend on the driving speed, so a constant driving speed over the whole section is desirable.



Figure 34_1. The Xsens MTi-G accelerometer (orange) and the GPS-receiver (black).

Acceleration measurements were carried out using an Xsens MTi-G accelerometer and integrated GPS-receiver. The accelerometer was attached to the right tire mounting, so that the suspension of the car did not affect the measured accelerations. During the measurements MTi-G measured accelerations at a frequency of 100 Hz (100 times per second). A constant driving speed of 40 km/h was used in the surveys.

The data analysis was carried out using Road Doctor™ software. The acceleration data was linked to the survey line and analyzed together with other road survey data. In the Road Doctor™ software 10 m deviation of the measured accelerations was calculated. The causes for the high accelerations were analyzed from the digital video that was also linked to the survey line.

3.5 Sampling

Samples / drill cores were taken on 13 separately specified sites. The sites were selected based on preliminary analysis of measured data. From the drill cores the thicknesses of each layer and grain size distribution of base course were determined. The points where samples were taken are presented in Table 35_1. The original drill core results are presented in Appendix 11. The drill cores were taken on lane 1 in the right wheelpath, except in section 2 at chainage 24 110m and in section 3 at chainage 43 260m. In those sections, samples were taken in the middle of lane because of cables and rut repair.

The drill core points are not always from same location (in transverse direction) than measured GPR lines, so they cannot be directly compared with each others.

Table 35_1. The drill core / sampling points.

Section number	Road number	Chainage [m]
1	1	64 600
2	1	22 300
2	1	24 110
3	1	43 260
4	3	83 300
5	3	199 875
6	2	150 690
7	4	58 350
8	4	145 650
8	4	146 500
9	4	131 450
9	4	133 700
10	9	59 980

4. Processing, Interpretation and Analysis

4.1 GPR Data

The GPR data was processed and interpreted with RoadDoctorPro® software. The digital video, laser scanner and accelerometer data were imported into RoadDoctorPro® for integrated interpretation and risk analysis.

The GPR interpretation carried out mainly follows the most important interfaces for this survey; the interfaces of layers which should be present according to design plans.

Interpreted layer thicknesses are compared to designed structures. The results are presented as statistics and as a map (Figure 41_1), where different colours represent the following situations:

- red – thicknesses are more than 10% thinner than designed
- green – thicknesses are between $\pm 10\%$ compared to designed structures
- blue – thicknesses are more than 10% thicker than designed

If the road structures are thinner than designed it is not causing any problems if well done.

In the following chapters a few examples of maps are presented. Maps of all interpreted layers are presented in Appendices. The longitudinal GPR data shown in Appendices are from direction 1, right wheelpath.

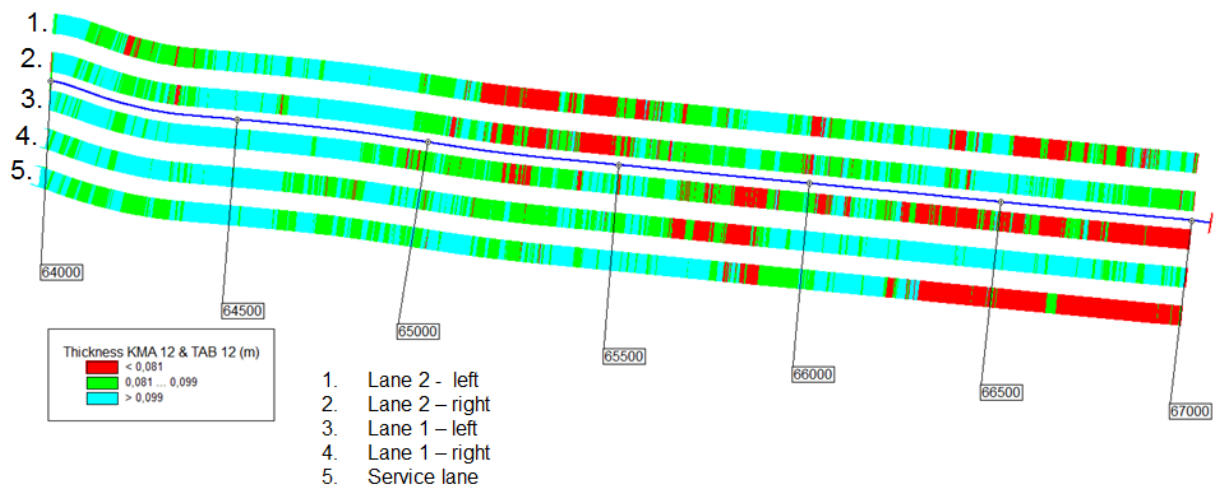


Figure 41_1. An example of interpreted structure thicknesses compared to designed thicknesses.

4.2 Laser Scanner Data

The laser scanner data was analysed as surface rainbow color maps (Figure 42_1) and surface elevation color maps (Figure 42_2). Changes in the surface topography of a pavement, compared to its normal shape, can indicate those areas suffering deformation or frost problems in the road. Usually these deviations in the road surface are not easy to discern visually. The use of a “rainbow map” however makes it considerably easier to visualize these deviations. These maps show road surface topography and its deviations and damage. The cross sections of roads were analysed also to find out the condition of ditches and slopes.

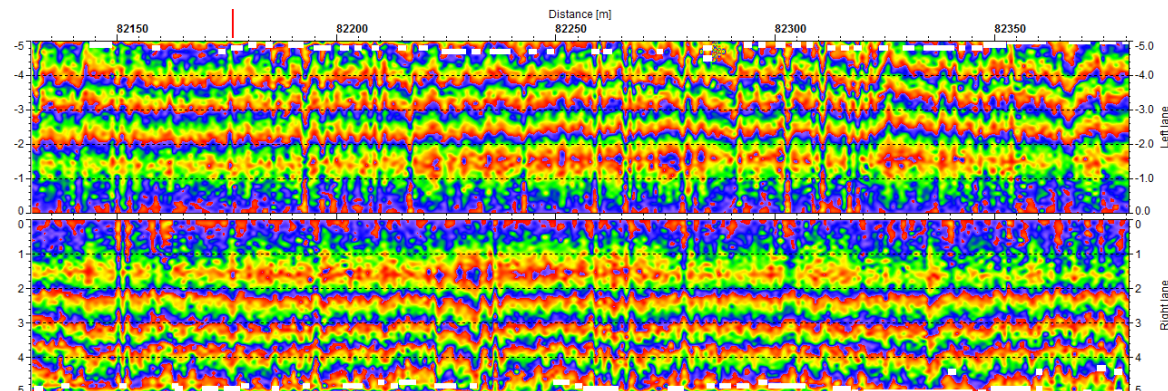


Figure 42_1. An example of a rainbow map with good crown section. Each complete colour palette represents 30mm change in surface level relative to the centerline.

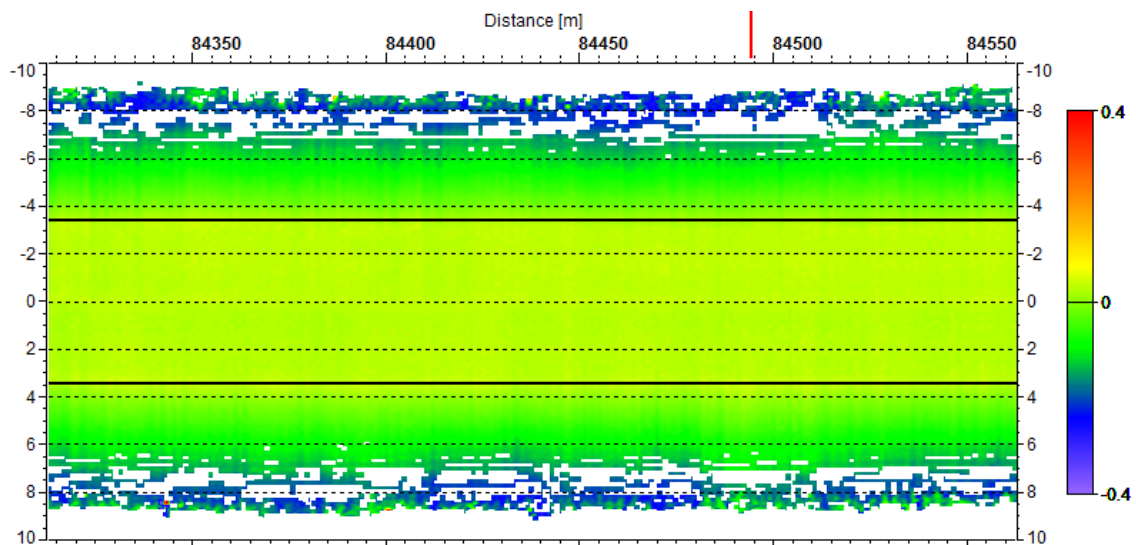


Figure 42_2. An example of a surface level color map of an even road section. Green and yellow colors represent the road surface – shades of blue represent the elevation below road surface and shades of red above it. The black lines on surface map represent the approximated road edges and have been used to better visualize the road shape.

Rutting was calculated from the laser scanner data using the wire rutting method and rutting was calculated using a running average over 5m distances. Rutting was analyzed from both driving lanes and from both wheel tracks (Figures 42_3 and 42_4). Figure shows also average rutting criteria. Average left and right wheel track and maximum rutting was calculated from the data. The height of the center between

the wheel paths and distance between rut bottoms was also calculated from the data. Statistical values of rutting from every section will be presented later in this report.

Rutting can be different because of many reasons; traffic amounts, driving behavior, amount of heavy trucks and their cargos, road materials, subgrade soils drainage, frost. One possible reason could be also road widening.

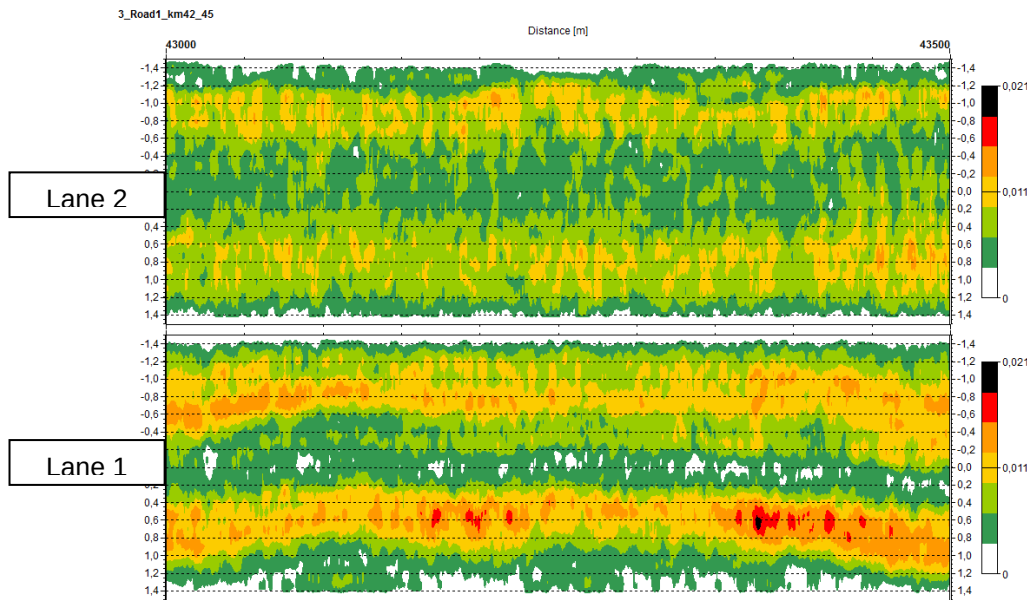


Figure 42_3. An example of rutting presented as longitudinal profiles. The detailed rutting profiles of each section are presented in appendices.

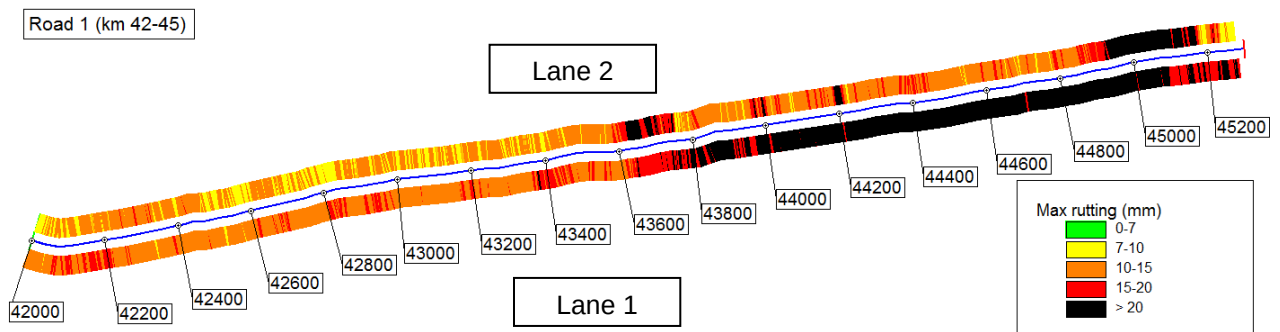


Figure 42_4. Maximum rutting from left and right wheel track from both lanes shown on map.

4.3 Accelerometer Data

Accelerometer data was analyzed as acceleration deviation calculated over 10m distance. High acceleration deviation means high longitudinal roughness. Approximate correlation with 10m IRI roughness is shown on the longitudinal profiles (Figures 43_1). The causes for high accelerations were analyzed from video and

compared with other survey data to find places with damages and deformation. Statistical values of accelerations from every section will be presented later in this report.

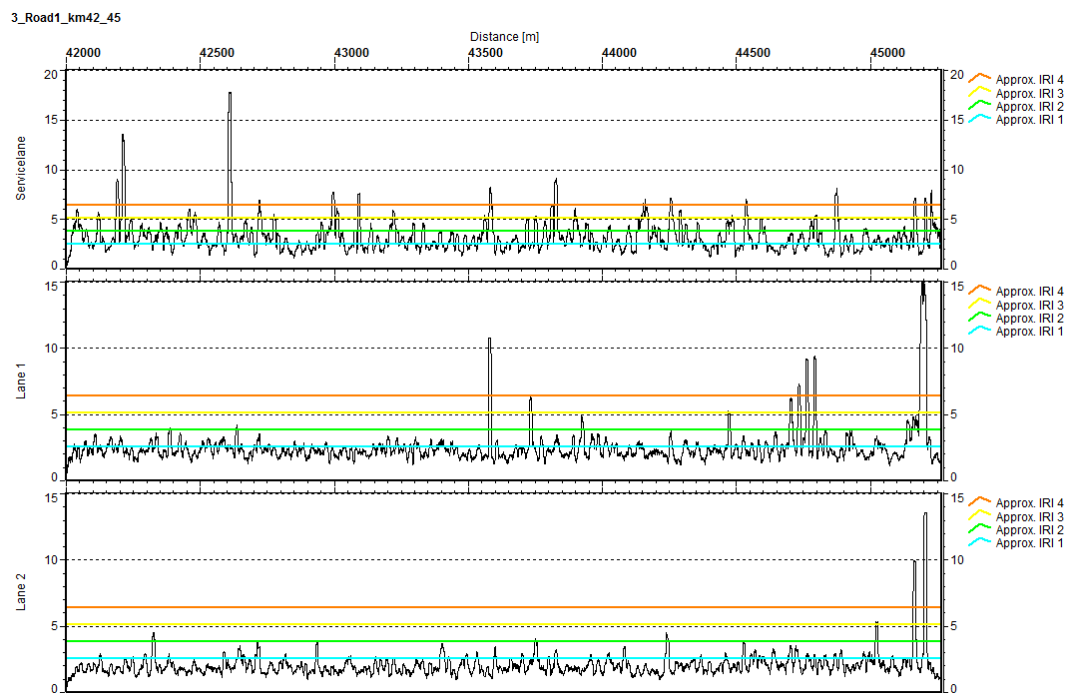


Figure 43_1. An example of approximate correlation with 10m IRI roughness in the longitudinal profiles. Blue line represents approximate IRI value 1mm/m, green 2mm/, yellow 3mm/m and orange 4mm/m.

Transverse cracks were visually located from the recorded video from the sections and they were compared to the absolute value of acceleration caused by the transverse cracks.

4.4 Drainage Evaluation

Drainage was generally evaluated visually from the video. The terms of drainage condition and road profiles are described in detail in Appendix 12. They are the same terms that have been used in ROADDEX projects.

4.5 Sampling

The drill cores were taken at specified locations by Reaalprojekt in September. From the samples different layer types and their thicknesses were observed. Material from the layer underneath the bound layers/base course was analysed by sieving to find out the grain size distribution. The detailed results are presented later in this report and the entire report is in Appendix 11. Also five samples from bound base course were analysed in laboratory to find out bitumen content. Samples were from sections 7-10. Results are analysed in chapters concerning the each section. According to

guidelines the residual bitumen content for bitumen stabilisation is usually 3-4 % but good results have been gained even by adding only 1 % bitumen to the base course. The bitumen content to be used depends mainly on the fines content.

4.6 Other

Riigikontroll also provided statistical roughness and rutting values from past years. The lifetimes based on this data were calculated on some level, but because the PMS data was inaccurate, including only 100m average values and some of the measured values did not make sense, the results were limited. Also bearing capacity values from the Estonian road data base were analysed from each test site. The life times were calculated also with Swedish PMS Objekt software (see Chapter 5.2).

5. Comparison of Standards in Estonia and some of the Nordic countries

5.1 Design in General

In Estonia, traffic volumes on some major roads are in average up to 9000 cars in 24 hours, maximum AADT can be much higher. In Finland, traffic volumes on major roads are between 3000 – 8000 cars in 24 hours. In Estonia the upper part of the road consists of wearing course (like $AC_{surf} + AC_{base}$ etc.) and unbound base and sub base (gravel, crushed stone) and drainage-course. When necessary some extra layers like frost protection, tanking layer, capillary block layer are also used.

Permanent pavements are calculated for 15 years in Estonia and for 20 years in Finland. In Finland the crushed rock made from hard bedrock material (made from igneous rock) is mainly being used. In Estonia there is a lack of good quality rock material and material with higher suction values are used. Limestone moduli value in Estonian road design norms during the design and construction phase of the tested sections was 400 MPa, which is, according to authors' opinion, too high, but can be explained through suction forces. In dry summer months limestone base aggregate modulus can be even 500 MPa but during the spring it can be as low as 100 MPa. Currently the moduli value of unbound limestone base course has been changed to 280 MPa in Estonia. Suction in granitic aggregates is lower and that is why changes are also smaller. General value is always a compromise of values during different seasons, In Finland and Sweden values like 280- 300 MPa are used at max – but this is matter of taste. On the other hand thickness of bound layers in tested roads in Estonia is so thick (at least on these surveyed 10 sections) that this allows somewhat poorer aggregate quality to be used because stress level is so much smaller in base course. A rule of thumb is that 200 mm or thicker bound layers allow use of slightly worse unbound aggregates than with thinner pavements.

5.2 Road Strengthening Design, Finnish Principles

In Finland the current guidelines for Road rehabilitation has been made in 2005 (TIEH 2100035-05). This document provides general guidance for the following issues:

1. How to set up goals for road strengthening project
This is made mainly based on traffic volume class and what type of damages appear on the pavement
2. What type of input data is needed for design and information about procurement options
This is based on what type of road damages are on the road, i.e. frost bumps, settlements etc
3. Traffic safety issues needed take into account during the design

4. Guidance for preliminary surveys

This gives what type of supporting information can be collected from road register and road condition data base and gravel road data base as well as from bridge data base. It gives also guidance how to make damage inventory in the field

5. Description of road survey methods and their analysis

6. Rehabilitation design principles

This provides information about the methods that can be used in design. The recommended methods are:

a) Odemark dimensioning method to target bearing capacity

This is used especially on heavy rehabilitation projects and on low volume roads and helps rehabilitation to focus on the weakest places in the road section. The problem is however how to calculate the old bearing capacity and after design new bearing capacity can be even lower than the old one.

b) Odemark method for increasing bearing capacity

This can be used if the goal is to lift bearing capacity on the design section at certain amount, for instance 40 MPa. This leads to 1-2 standard structures in the whole project

c) Analytical dimensioning method

This allows using analytical dimensioning software packages to use the design based on stress and strain calculations. This can be made when pavement thickness is > 80 mm

d) Method based on the speed how pavement distress index is increasing

This is recommended to be used in certain stabilization projects and/or when the base course material quality is poor.

This chapter gives general guidance how to calculate bearing capacity of the road. It has many “rules of thumbs” based for instance how much distress old pavement has, what is the bearing capacity of old road, what is the bearing capacity of the road during spring thaw etc.

This chapter provides also information about the rehabilitation options that can be used in strengthening, such as new aggregates, new overlay on the top, stabilization, mixmilling, the use of geogrids and steel grids etc. Also information about options for fixing different kind of damages is given. Instructions how to improve drainage option are also given.

7. Principles for road widening

The last chapter provides instructions for road widening. This is quite good and unique guideline and according to ROADDEX project benchmarking there are hardly any guidelines for road widening in Northern Europe.

The dimensioning principles are given in the appendix of this report and there are tables for how to calculate corrected old bearing capacity based on bearing capacity measurement results. Report gives also guidance for moduli values for each rehabilitation option. The appendix presents also tables for theoretical spring thaw capacity requirements for different rehabilitation options.

When discussing about design bearing capacity this guideline refers to the road design guidelines based on the traffic volume and road class referred in the new road design guidelines. But in practice these values are not required to be used and judgments for each road is made case-by-case based for instance on the resources given to each project and each road district can define independently the level of the road strengthening.

5.3 Road Strengthening Design, Swedish Principles and Practices

In Sweden the current guidelines “Förstärkningsåtgärder, Vägverket Publikation 2008:15” were published in 2008 and it has been written to be a handbook which gives tips and instructions how to perform a road strengthening or rehabilitation project. It has especially detailed instruction how to perform field surveys to collect proper input data. The previous guidelines were made in 1992. The guidelines have the following chapters:

1. Introduction
2. Description what is road strengthening project
3. Guidelines for road inventory
This old guidelines focuses mainly on the designers site visit and visual inspections of the road condition and environment around it.
4. The goal for the project
There is a short description of the quality goal
5. Official processes
This chapter describes about the official (legal) issues related to road strengthening.
6. Project goal description
This chapter gives a description what consult has to do in the project
7. Reporting during the design process
8. Design input data - description of current road and environment
This chapter gives guidelines about the description of current road condition and traffic including also meteorological data and traffic accidents. The description of Swedish road data bases can be found in this chapter. Chapter has numerous photos describing different kinds of road damages and their reasons. Finally different road survey methods are briefly described in this chapter.
9. Calculation and design principles
This chapter provides general information about how to perform design and dimensioning of the road structures including also drainage design. This chapter refers PMS Objekt software when dimensioning the rehabilitation structures. General principle is that pavement structure should be designed for 20 years and embankment/subgrade for 40 years but other life times can be used case-by-case. Design is made point like and this design structure will be used in homogenous road sections defined by design engineer. In this chapter there is also a short description of road widening.

These guidelines are currently being rewritten especially because new road survey techniques and diagnostics methods have replaced the old methods used earlier. Also new GPS positioning techniques provide new possibilities for more precise design. The new handbook is currently on test use it will be most likely published in 2013.

The dimensioning of a new and rehabilitated road should be made using PMS Objekt software which is an analytical-experimental software based on linear elastic theory. It calculates also frost heave. PMS Objekt software is described in detailed in article

“A New Approach to pavement design in Sweden, new Swedish road Design Manual” by Thomas Winnerholt in the proceeding of BCRA Lisbon 2002. Winnerholt describes the system in the following way:

The basic idea behind the layout is that for every single road project there will be several different sections for which the design parameters are slightly different. Therefore a project has to be created within the program. The project is the common link for all the different sections along the road design project.

There are two basic types of sections; the section is either a new construction or a maintenance and rehabilitation section. Since the manual deals with these two types differently it's a very important difference. The differences between new construction and maintenance and rehabilitation are, for example:

- *Old materials and layers have to be evaluated and given properties according to their present state.*
- *Old pavement can be defect but the economic side of the project demands that a cracked layer is left in the pavement.*
- *When a maintenance and rehabilitation measure has to be done the existing pavement has some strength left and that has to be taken into account when designing the measure.*
- *New construction gives the opportunity to control the drainage facilities.*
- *New construction allows for higher and more specified demands on materials and layers.*

Each section is then given a number of section specific characteristics. After that process is done the actual pavement design can start.

After establishing the project the software requires traffic calculations to be done. Then, in the case of new road, a new pavement structure can be designed based on different material properties and different structure thickness. The software calculates the allowable axle loads based on fatigue models and it calculates horizontal and vertical strains in pavement bottom and on the top of subgrade. The software has a unique traffic light system to show if the design passes the requirements (figure 53_1). Unlike in Finland and Estonia there are no target bearing capacity values in this system so direct comparisons cannot be made.

In addition to pavement life time design PMS Objekt has also a frost design feature that uses the areal temperature data, frost susceptibility evaluation of each road material and drainage condition.

This Swedish PMS Object software is, according to authors, the best design system in Nordic countries and it is also used in project level surveys in Finland and in Norway. However the current practice in Sweden is that, due to limited financial resources, the designed structures, given by PMS Objekt cannot be always made and in practice the life time of roads are not as long as predicted.

Figure 53_1. An output screen from PMS Objekt. “Traffic lights” show if the structure is acceptable or not.

5.4 Comparisons with Estonian Practices

Summary of used moduli values in Estonia and Finland is presented in Appendix 13. A few examples of typical structures used in Estonia were calculated with PMS Objekt. In the calculations, modules according to Estonian guidelines and values from PMS Objekt, were used.

If the calculated strength is different from that which is allowed, then the overlay/pavement has to be redesigned. Calculating an elastic collapse the cover/pavement is handled as one body.

Estonia has also design procedure against frost heave and minimum thicknesses of the constructive layers are defined to ensure that the road surface would be thick enough and to deal with the frost heaves. See Table 54_1.

Table 54_1. Minimum thicknesses of constructive layers. Source of information: http://www.mnt.ee/failid/juhised/elastsete_teekatendite_projekteerimise_juhend.pdf

Material of the Layer	Max grain size D_{max} , mm	Min Thickness
Dense asphalt concrete	4 või 8 12 või 16 20 või 32	3 – 4 3 – 5 6 – 7
All porous asphaltconcrete sorts	16 32	4 – 5 6 – 7
	8 16 või 20 32	4 – 5 4 – 6 8
Drainasphaltconcrete		2
KMA- crushed mastic asphalt		3 või $2 \cdot D_{max}$
Valusafalt		$2 \cdot D_{max}$
Bitumen stabilized layers		8
Cement and complex stabilized layers		12
Black mixes: from the mixer		5 – 7
Mixed on the way		8
Bitumenmacadam - deep impregante		6,5
Bitumenmacadam - easy impregante		4
Gravel coat	12 16 20	4 5 12
Unmanufactured crushed stone and gravel-sand subgrade: fortified layer		12 20
Sand		

Sand (as a drainage layer)

20

The strength of technical layer material cannot be worse than the layers which it is laid on. Strength and frost properties of materials generally used in Estonia are presented in Table 54_2. Calculations are based on dynamic loading of the road.

Table 54_2. Overlay/pavement dynamic load and frost strength calculating diagram. "Siirde" cover is transfer pavement. Source of information: http://www.mnt.ee/failid/juhised/elastsete_teekatendite_projekteerimise_juhend.pdf

Cover/ pavement	For strength in dynamic loading				All cover/pavement for frost strength
	All cover to elastic collapse	Soil for shear strain	Asphaltconcrete layers worked with mineral and complexed binders for tensile strength	Building materials without working with binder(not crushed stone) for shear strain	
permanent cover	+	+	+	+	+
lightweight cover	+	+	+	+	+
"siirde" cover	+	+	-	-	+
Regular cover	+	-	-	-	-

In the comparison calculations average and estimated pavement structure information for each section were used in calculations made with PMS Objekt. The utilized source information and the results of the calculations are presented in Table 54_3. According to calculations most of the sections fulfil the required PMS Objekt 15

years lifetime. More discussion about the results is given in chapter 8 “Summary and Conclusions”.

Table 54_3. The source information used and results of calculations from PMS Objekt for each section.

Section	AADT	Heavy	% Heavy	Structure [mm]					Subgrade	Theoretical lifetimes	
				Pavem.	Other bound	Base	Subbase	Other		Bound layers	Foundation
1	5692	864	15.2	90	120	180	300	250	Clay	>>30	>30
2	11700	864	7.4	80	200	200	200	270	Silt	>>30	14
3	11700	864	7.4	90	150	220		230	Sand	>>30	>30
4	2252	296	13.1	90	200			300	Sand	>>30	>>30
5	2175	296	13.6	90	150			250	Moraine >30%	>>30	5
6	6031	835	13.8	140	250			1000	sand	>>30	>>30
7	6408	1267	19.8	100	300			300	Moraine >30%	>>30	>30
8	3671	1267	34.5	150	150			400	clay	>15	9
9	7628	1267	16.6	220		200		700	sand	>30	>>30
10	3095	268	8.7	100		120		750	Moraine >30%	4	>15

Theoretical lifetimes can be understood to be the time, when the material’s physical properties have changed so much, that they do not meet the requirements any more. This leads to a high risk of failure in functional condition of the road. Section 4 was chosen for detailed calculations to find out what effect the Estonian rehabilitation operations would have on the road lifetime according to Swedish principles. The calculations were made with average thickness values and estimated strength information. The results showed that lifetime of initial (old) structure would have been 6 years for bound layers and 3 years on the foundation level (Figure 54_1). After the strengthening with new bound layers (TAB 12 I 4cm, PAB 16 5cm and KS 32 (stabilisation)) the lifetimes exceed the required 15 years.

The screenshot shows the 'Remaining bearing capacity' software interface. It has four tabs: 'Results' (selected), 'Compare axle loads', 'Comparison singular load', and 'Strain results in detail'. The 'Results' tab contains the following information:

- Correction factor that takes moisture and water in the sub-grade into account:** Correction factor f_d : 0.8. A note states: 'If the correction factor has been changed it is advisable to note why the change has been made in the section notes.'
- Calculated theoretical life span:**
 - Bound pavement: 6
 - Foundation level: 3
 - Passed ESALs (Np): 213 744
- Number of ESALs, accumulated:**
 - Horizontal tensile strain in the under side of bitumen bound layers: Ntill,bb: 1 646 955; Nekv: 3 474 547. Status: Red circle.
 - Compression strain on the foundation level: Ntill,te: 1 623 159; Nekv * 2: 6 949 094. Status: Red circle.
- Vertical compression strains, singular load:**
 - Compression strain on the foundation level: maximum allowed: 0.002500; Calculated: 0.001366. Status: Green circle.
- Analyze the pavement as a:**
 - Flexibel Pavement: ☒ GBO/BBO, ☐ User defined
 - Rigid Pavement: ☐ CBO, ☐ BO

At the bottom are buttons for 'Calculate', 'OK', and 'Cancel'.

Figure 54_1. The lifetimes of section 4 with initial structure before rehabilitation.

Calculations with PMS-Objekt were performed for all the sections in this project. The calculations were made with the average and estimated information of each section. The source information utilized and results of the calculations are presented in Table 54_3. According to calculations most of the sections fulfil the 15 years lifetime requirement.

Frost Heave standards:

In Finland the maximum allowed calculated/expected frost heave depends on the class of the road, the amount of traffic on the road, speed limit, use of steel net reinforcement, whether structure is normal or other (boulder, cement stabilized or includes cellular plastic) and whether the subgrade is homogenous or not. Finnish standards are shown in Table 54_4. In Estonia maximum allowed calculated/expected frost heave depends on the structure:

- permanent/"püsikatendid" 4cm
- lightweight/"kerekatendid" 6cm
- transfer pavement/"siirdekateid" 10cm
- macadamized gravel/"pinnatud kruuskatted" 6cm.

Table 54_4. Allowed frost heaves in Finland

(<http://alk.tiehallinto.fi/thohje/pdf/2100029-v-04tierakenteensuunn.pdf>)

	Maximum allowed calculated expected frost heave (mm)					Inclination of transition wedge 1:k (for sandfilled, for boulder filled k=1,5*sandfilled)
	Homogenous subgrade			Non homogenous subgrade		
	No steel net		Steel net	No steel net	Steel net	
	Normal struct.	Boulder etc.				
Motorway	30	30	30	0	0	1:40
Main road 80-100 km/h	70	70	100	10	10	1:30
Regional road 80-100 km/h <u>and</u> traffic flow > 1000 cars/24h	100	70	130	10	10	1:20
Regional road 60 km/h <u>or</u> traffic flow < 1000 cars/24h, Local road traffic > 1000 cars/24h	130	70	160	30	100	1:15
Local road traffic flow 400-1000 cars/24h	160	100	no max.	70	130	1:15
Road with kerb <u>or</u> sewerage, 80 km/h, traffic > 1000 cars/24h	30	30	30	10	0	1:30
Road with kerb <u>or</u> sewerage, 50-70 km/h, traffic > 1000 cars/24h	70	70	100	10	0	1:30
Road with kerb <u>or</u> sewerage, < 50 km/h, traffic < 1000 cars/24h	Local authority's own standards					
Separate paved pedestrian and bicycle way	70	70	160	30	130	1:10
Raised pedestrian and bicycle way	Same as driveway					

Maximum allowed frost heave for motorways is lower in Finland than in Estonia. In Finland maximum allowed frost heave for motorways on homogenous subgrade is 30 mm and for non-homogenous subgrade 0 mm, as in Estonia maximum frost heave for motorways (permanent/"püsikatend" structure used) is 40 mm.

Generally maximum allowed frost heaves have a little variation between the two countries. The rules are more complicated in Finland: For example if steel net is used, maximum allowed frost heave is higher (in some cases).

In Sweden the frost heave calculations with PMS Objekt software are based on different climate zones. With the traffic amount 10000 (includes 14% heavy vehicles), new construction and moraine subgrade, the maximum allowed frost heave is 80 mm. For rehabilitated roads the allowed maximum frost heave is 160mm.

5.5 Road Performance specification

5.5.1 Rutting performance

The critical limits for maintenance operations vary between different countries. The traffic amounts for the roads surveyed in this study vary approximately between 1500-5000 vehicles/day. The critical limit for rutting is 20mm (100 m average) in Estonia and Finland. In Norway the limit is looser, 25mm in every road class. In Sweden and in Denmark the limit is lower, 10mm in Denmark and 17mm in Sweden. In Finland the demand for rehabilitation / repaving operations will launch if 10% of the section has greater values than the critical limit. A comparison of the standards from different countries is presented in Figure 55_1.

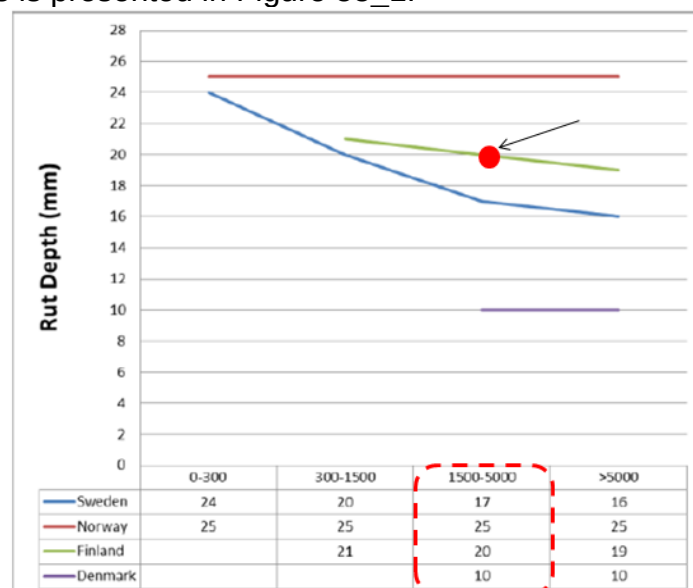


Figure 55_1. A comparison of maintenance standard for rut depth in the Nordic countries. The critical limit (20mm) and the class of the surveyed roads in Estonia are marked with red color. Note that presented values are average values of 100m.

5.5.2 Roughness performance

Critical limit of roughness (IRI) is 4mm/m (100 m average) in Estonia and Sweden. In Norway and in Finland the limit is higher; 4.5 mm in Norway and 4.2 mm in Finland. In Denmark the limit is tightest, 2.5mm. In Finland and in Sweden the need for rehabilitation / repaving operations will be triggered if 10% of the section has greater values than the critical limit. A comparison of standard values is presented in Figure 55_2. According to information based on Estonian road design norms the limit for roughness seems to be stricter, 1,5mm/m on road class 1 (Figure 55_3).

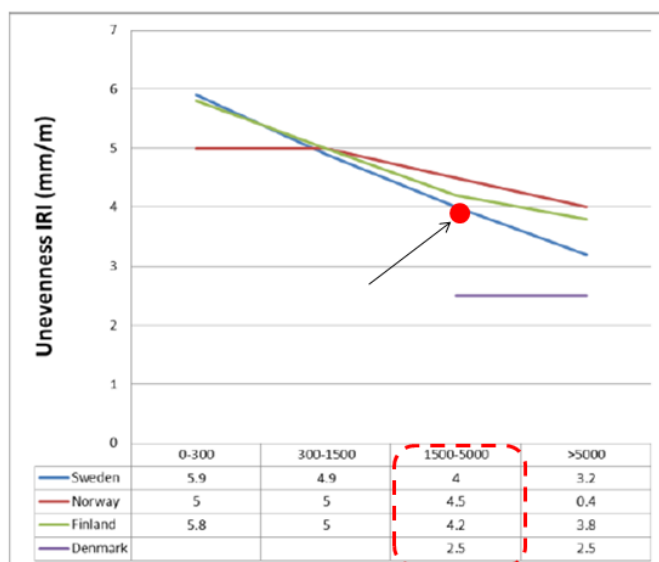


Figure 55_2. A comparison of maintenance standards for roughness in the Nordic countries. The critical limit (4mm) and the class of the surveyed roads in Estonia are marked with red color. Note that presented values are average values of 100m.

Nõuded teepinna tasetasusele

Maantee klass	IRI suurim lubatud väärtus, mm/m		
	Põhiteed	Tugiteed	Kohalikud ja muud teed
Kiirtee	1,5	—	—
I–II	1,5	2,0	—
III	2,5	3,0	3,5
IV–V	—	4,0	4,5

Figure 55_3. Limits for roughness values in different road classes according to Estonian road design norms.

5.6 Road design comparisons

A calculation exercise was also made in order to compare design systems between Estonia, Finland and Sweden on high traffic volume roads. The basic design input information used in defining typical structure types in Finland, Sweden and Estonia was as following: AADT (average daily traffic) 10 000 cars, which include 14 % heavy traffic. Subgrade type was moraine (till) with high fines content ($> 30\%$). The Swedish design structure was defined with PMS Objekt, the Finnish structure was based on information of guidelines “Tiehallinto: Tierakenteen suunnittelu”, 2004. The calculations of Estonian structures were made according to Estonian design norms by Ain Kendra, Senior Advisor of Ramboll Estonia and a Lector of Tallinn University of Technology. The results are given in the following.

5.6.1 General

The total pavement structure thickness varies a lot in different countries. The thinnest recommended structure is in Sweden (900mm) and the thickest in Finland (1590mm). On the other hand the bound layer thicknesses is vice versa; in Finland design procedure recommends 170mm and in Sweden 210mm. Table 56_1 presents the summary of thicknesses in each country. Figures 56_1-3 present the structure of each country and they are reviewed detailed in following chapters.

Table 56_1. Bound layer and total structure thickness in each country.

Country	Thickness [mm]	
	Bound layers	Total structure
Estonia	190	1070
Finland	170	1590
Sweden	210	900

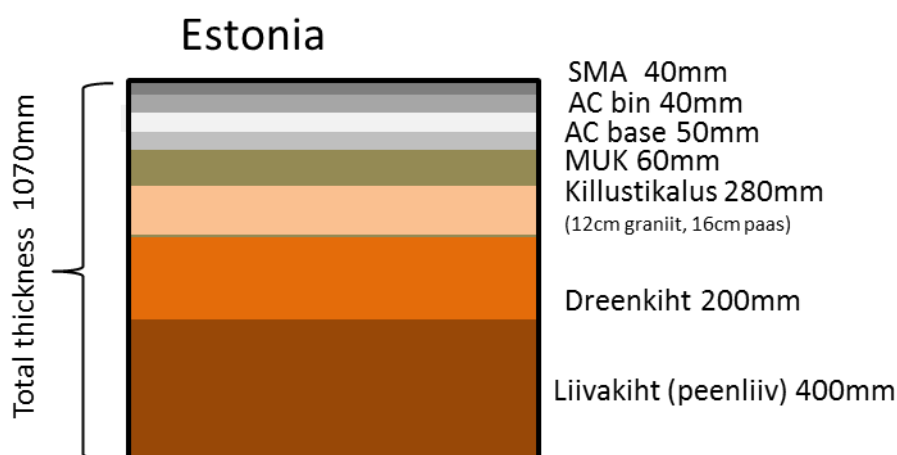


Figure 56_1. Typical structure in Estonia with road parameters defined in the first chapter.

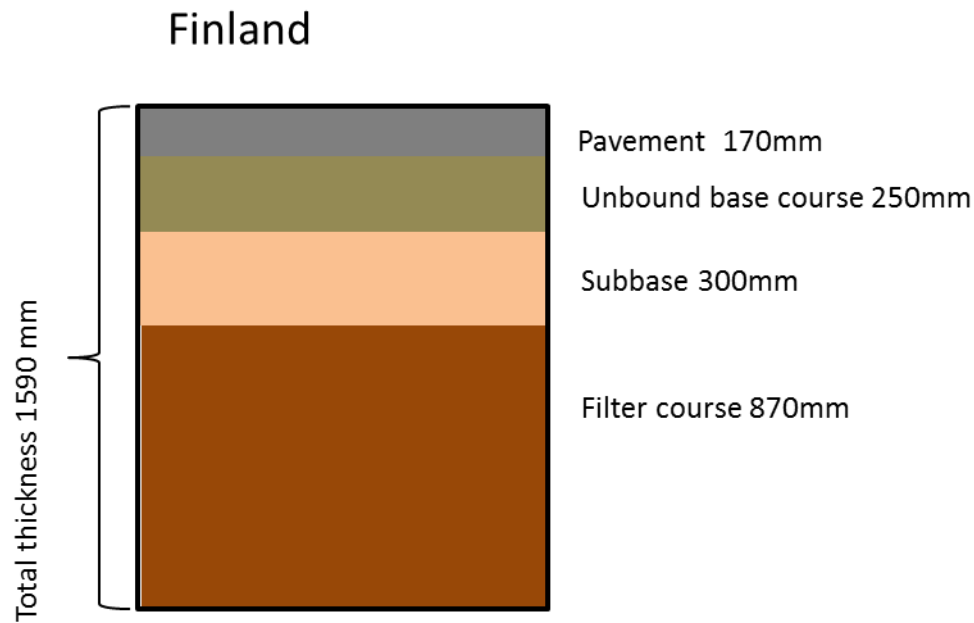


Figure 56_2. Typical structure in Finland with road parameters defined in the first chapter.

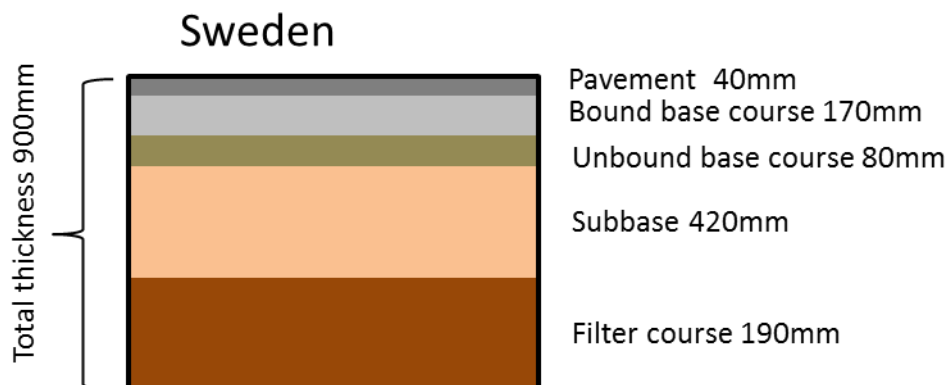


Figure 56_3. Typical structure in Sweden with road parameters defined in the first chapter.

5.6.2 Bound Layers

In Estonia the structure consist of four different bound layers: SMA (40 mm), ACbin (40 mm), ACbase (50 mm) and MUK (60mm), which compile in total 190 mm. For Swedish pavement structure it is typical that bound layers consist of two layers pavement: 40mm wearing course and 170 mm bound base course. In Finland the total thickness of bound layers is 170 mm and typically it consist of following separate courses: bound base and wearing course.

5.6.3 Other Road Structure

Typical feature for Swedish road structures is a very thin unbound base course, which is according to guidelines only 80 mm. The Finnish structure includes the 250 mm unbound base course. In Estonia beneath the bound layers can be found 280

mm of killustikalus layer, which consists of 120 mm graniit and 160 mm paas (=limestone). When comparing unbound base+subbase structure thicknesses of each structure, the Estonian structure has the thinnest thickness. In Estonia their total thickness is only 280 mm, in Finland 550 mm and in Sweden 500 mm. The Estonian subbase has been defined to be limestone (paas).

Finnish structure has a special filter course layer, normally made of sand, which has thickness of 870mm. In Sweden this layer is thinnest (only 190 mm). In Estonian structure “dreenkiht” 200 mm and “peenliiv” (=fine sand) 400 mm can be seen as filter course, when their total thickness is 600 mm.

5.6.4 Bearing Capacity

Estonian expert calculated also the bearing capacities of Finnish and Swedish pavement structures using Estonian dimensioning method. According to these calculations the Estonian structure has a bearing capacity of 277 MPa. This fulfills the requirement, which is in Estonia 240 MPa on road class I. The bearing capacities of Swedish and Finnish structures are much higher; 352 MPa (Swedish) and 435 MPa (Finnish). According to Finnish guidelines the bearing capacity of Finnish structure is 420 MPa. See Table 56_2.

Table 56_2. Bearing capacities of structures calculated with Estonian dimensioning method.

Country	Bearing Capacity [MPa]
Estonia	277
Finland	435
Sweden	352

5.6.5 Conclusions

The Estonian structure was compared to Finnish and Swedish structures. Estonian structure has several separate thin layers. The total thickness was slightly higher than in Swedish structure. The difference is in quality of used materials, because the Swedish structure has higher bearing capacity than Estonian structure. Both bearing capacities were calculated according to Estonian dimensioning guidelines. The Finnish structure is about 50 % thicker than the Estonian structure. The main difference is in base and subbase course thicknesses, which in practice mean that the Finnish structure can be more resistant against mode 2 rutting in road structure subgrade interface. In Estonia the total thickness of crushed unbound base material was about 50 % thinner than in other countries. This can be explained by lack of good quality material in Estonia. Crushed bedrock aggregates are used widely in Finland and Sweden while in Estonia also limestone is used.

6. Results

The results of each surveyed section are presented in following chapters. The detailed longitudinal profiles are presented in separate appendices. This report does not provide separate comments about the laboratory results and material properties of the samples taken.

In general it can be said, based on grading curves, that most of the materials from the base course have "sand bag" which means too much coarse sand/fine gravel. All base course samples have fines ($<0,063\text{mm}$) less than 10%, but more than 4%. It means that suitability for base course material depends on quality of the fine material. The Grain Size Curves are presented in Appendix 11.

6.1 Section 1 – Road 1 km 64-67

Road section 1, road 1 from km 64 to 67, has been rehabilitated in years 2009-2010. Road 1 goes from Tallinn to Narva. The rehabilitated section was from Liiapeksi to Loobu and in this study the section Valgejõe – Läsna was examined.

The road section has been rehabilitated with a strong structure and the road section is in very good condition without damage. Drainage is in good condition.

6.1.1 Designed Structure

Table 61_1 presents the designed structures, which should have been implemented in the rehabilitation process. The information is based on detailed plans and other information provided by Riigikontroll.

Table 61_1. The detailed plan information from section 1.

Structures location in the survey area	64 - 65,126	65,126 -67
Pole number	612+ 74...624+00	624+00...642 + 74
Lenght of structure type	1,126 km	1,874 km
Materials	Thickness [cm]	Thickness [cm]
Stone Mastic Asphalt KMA 12	4	4
Dense Asphalt concrete TAB 12II (with granite)	5	5
Open graded asphalt concrete PAB 16	6	6
Pre-coated chippings MUK 12-32	6	6
Crushed Granite mix (0/63)	20	20
Gravel sand base	20	
Fine sand embankment	20	
Existing gravel sand or crushed stabilized base		x
Existing soils	x	
Total thickness [cm]	81	41

6.1.2 GPR

Mostly the layers fulfill the designed structure demands. Some deficiencies are detected, especially concerning the base course. Base course thickness is more than 10 % under planned, varying between 41-68 % of distance per survey line (see statistics in Appendix 1) and on average the undershoot is about 4-5 cm (in the more than 10 % under class). The fine sand embankment at the beginning of the section is also mostly thinner than it was planned to be. The layer thicknesses between different measured lines are at quite the same level, but some small variations can be seen. An example map presentation of layer thicknesses is shown in Figure 61_1. All maps and statistics of interpreted layer thicknesses are presented in Appendix 1.

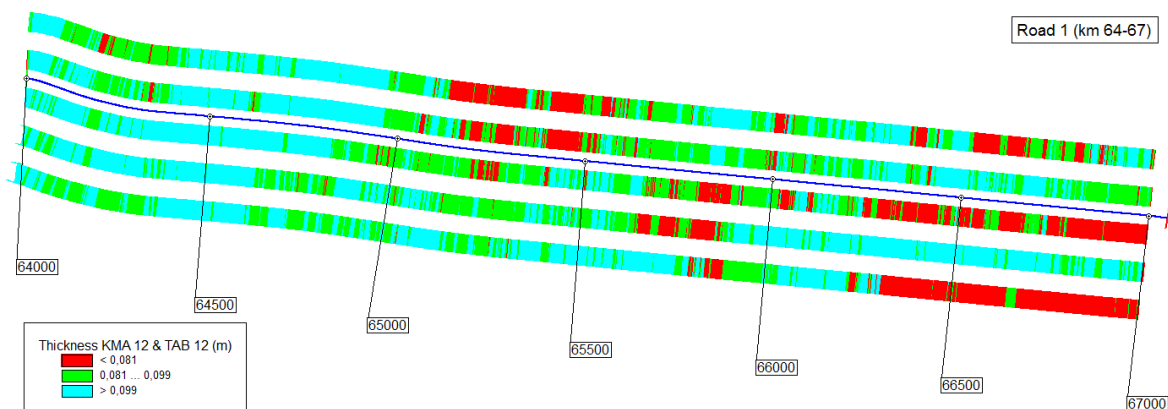


Figure 61_1: The interpreted layer thicknesses of KMA12 and TAB12. Thicknesses have been classified into three classes: red – thicknesses are more than 10% thinner than designed; green – thicknesses are $\pm 10\%$ compared to designed structures and blue – thicknesses are more than 10% thicker than designed. The topmost line represents measured line in lane 2 on the left wheelpath, followed by other wheelpaths until the service lane (lowest line).

The GPR interpretation showed that designed thicker structure ends 35m earlier than it should. According to plans the structure should end at chainage 65 126m, but it ends approximately at about chainage 65 090m (Figure 61_2). The missing amount of both materials is about 100m³.

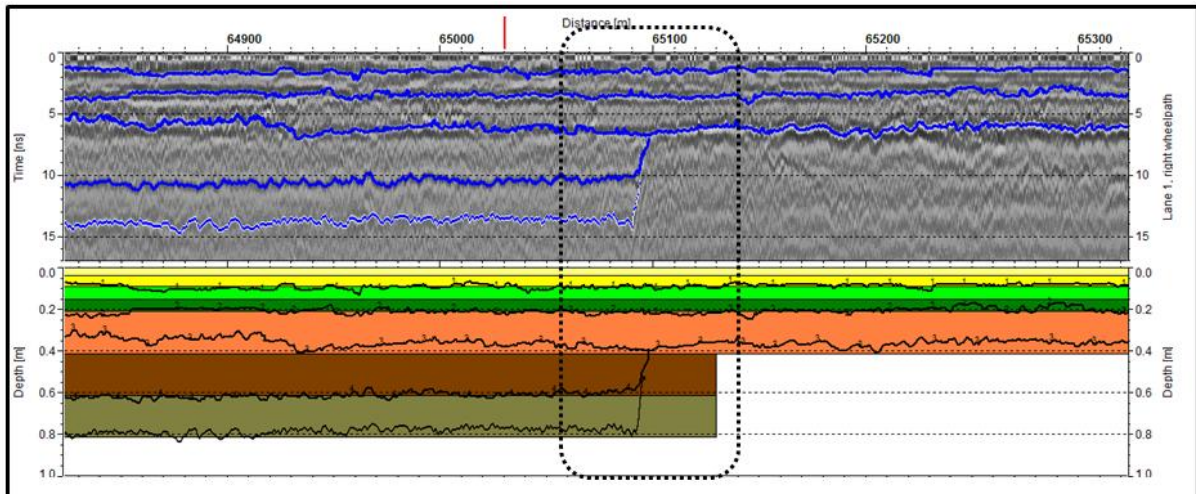


Figure 61_2. The thicker structure ends earlier than designed. Colour bars represent the design structure and black/blue lines the interpreted structures.

GPR interpretation also showed that from chainage 66 185m to 66 740m the base course (Graniitkillustik optimaalne segu 0/63) has been built in two shifts (Figure 61_3). The clearest interface is seen on lane 1. The possible reason for this could be that the layer has been temporarily under traffic during the construction work. This has no effect on road condition seen on road surface.

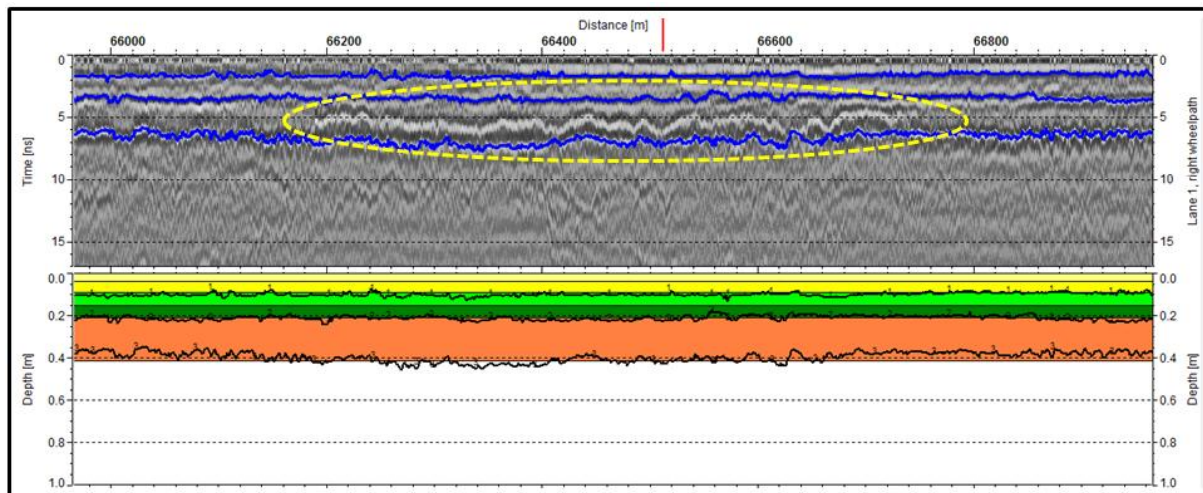


Figure 61_3. From chainage 66 185m to 66 740m the base course (Graniitkillustik optimaalne segu 0/63) has been built in two parts.

6.1.3 Laser Scanner

The analysis of laser scanner data shows that road surface is quite even with good cross section. Detailed cross section of laser scanners data is presented in Appendix 1.

6.1.4 Accelerometer

Road surface is in very good condition. It has been paved recently and there is no significant damage that could be seen in the accelerometer data (Figure 61_4). There are no big acceleration spikes that can be seen in the 10m acceleration deviation data. There are some small spikes in the service lane acceleration data, but they are caused by gravel and dirt that is on the pavement (Figure 61_5).

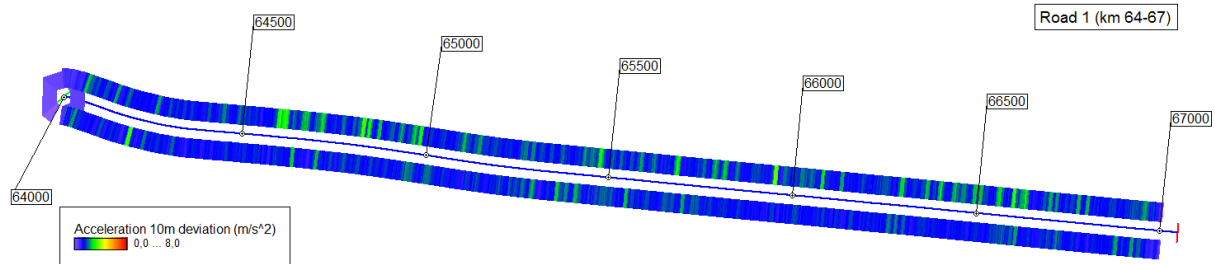


Figure 61_4. Acceleration 10m deviation from section 1 presented as a map.

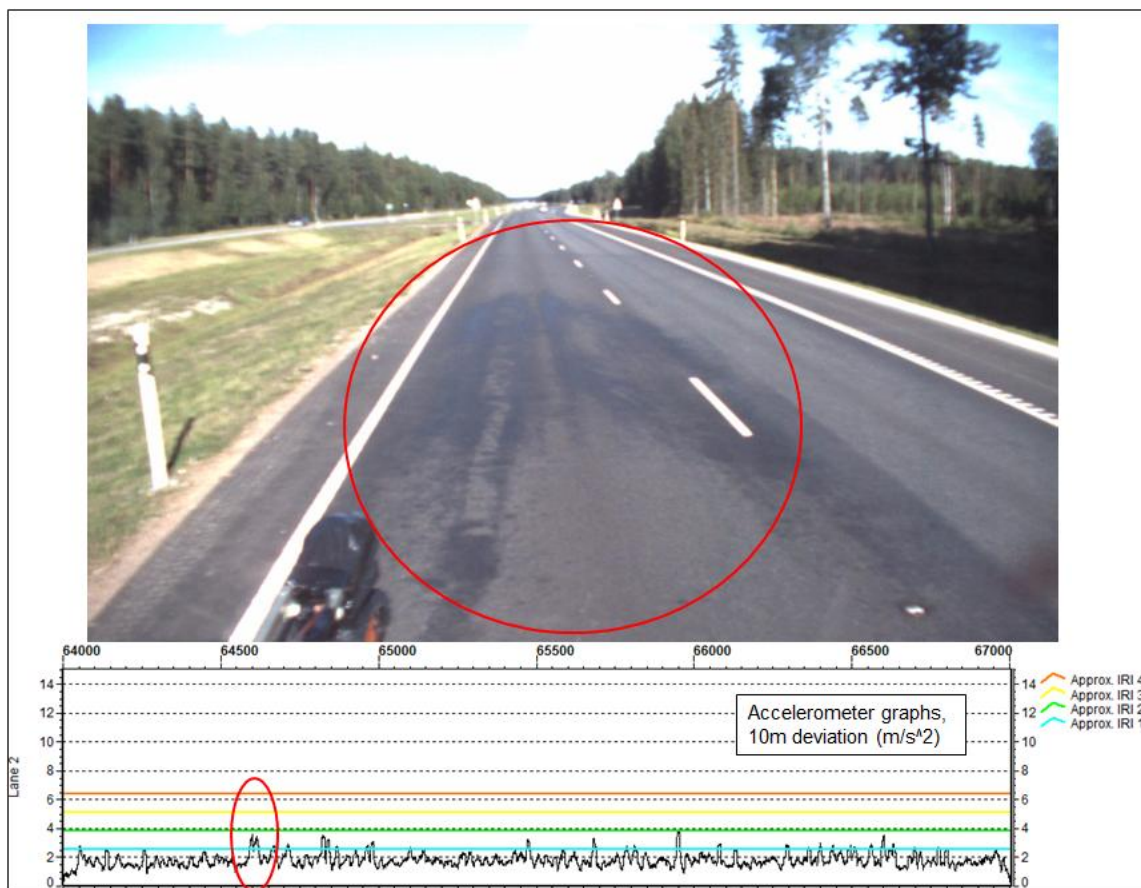


Figure 61_5. Very small imperfections in lane 2, at chainage 64600m.

6.1.5 Rutting

The road surface is in good condition. Rutting is low in whole section. Detailed results are presented statistically in Table 61_2 and as a map in Figure 61_6.

Table 61_2. Statistical results of rutting from section 1.

	Lane 1	Lane 2
Left rutting aver. (mm)	7,6	8,1
Right rutting aver. (mm)	7,5	6,9
Max rutting (mm)	12,8	15,9
Aver. height of the ridge rut (mm)	9,6	7,7

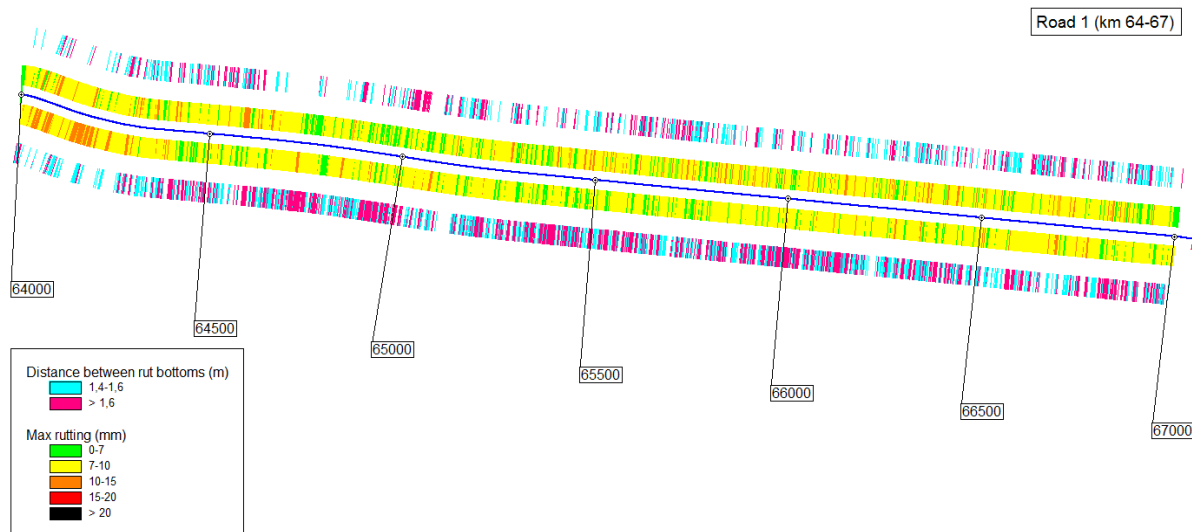


Figure 61_6. Maximum rutting in both lanes (inner lines, colours from green to black) together with distance between rut bottoms (outer lines, colours pink and blue).

The results of this analysis could not explain fast rutting problems in section 1. One possibility is that the rutting is so called Mode 0 rutting, which means that asphalt is getting compacted due to high amount of air voids during the paving process. This however cannot be clearly shown afterwards.

6.2 Section 2 – Road 1 km 22-25

The road section 2, road 1 from km 22 to 25, has been rehabilitated in years 2005-2006. Road 1 goes from Tallinn to Narva. The rehabilitated section was from Maardu to Valgejõe and in this study the section Maardu - Kodasoo was examined.

Road is in fairly good condition with small defects. A reason for damages could be poor drainage, because drainage is not functioning everywhere and verges can be detected in both edges. However, this can be also a maintenance issue. Road has a lot of ruts, which have been patched, especially in lane 1. The road section has been rehabilitated with simple structure of adding only new pavement layers.

6.2.1 Designed Structure

Table 62_1 presents the designed structures, which should have been implemented in rehabilitation process. The information is based on detailed design and other information provided by Riigikontroll. According to design the road has been strengthened by laying two new bound layers.

Table 62_1. The detailed design information from section 2.

Structures location in the survey area	22 - 25
Temp. chainage according to the design	193+30...223+30
Length of structure type	3 km
Materials	Thickness [cm]
Stone Mastic Asphalt KMA 12	4
Dense asphalt concrete TAB 16 II	4
Existing asphalt concrete	12
Existing crushed limestone base	24
Existing embankment	x
Total thickness [cm]	48

6.2.2 GPR

The new pavement layers mainly fulfill the designed thickness, but some undershoot was detected. Pavement thickness is more than 10 % under planned varying between 29-40 % of distance in the survey lines. Especially in driving lane 1, the places where the thinnest pavement is found, also have the highest roughness and rutting values in the section. Maps and statistics of interpreted layer thicknesses are shown in Appendix 2.

6.2.3 Laser Scanner

Laser scanner data showed that road surface is quite even, but small verges were on both sides in some places. The verges prevent the water from flowing away from the road surface (Figure 62_1).

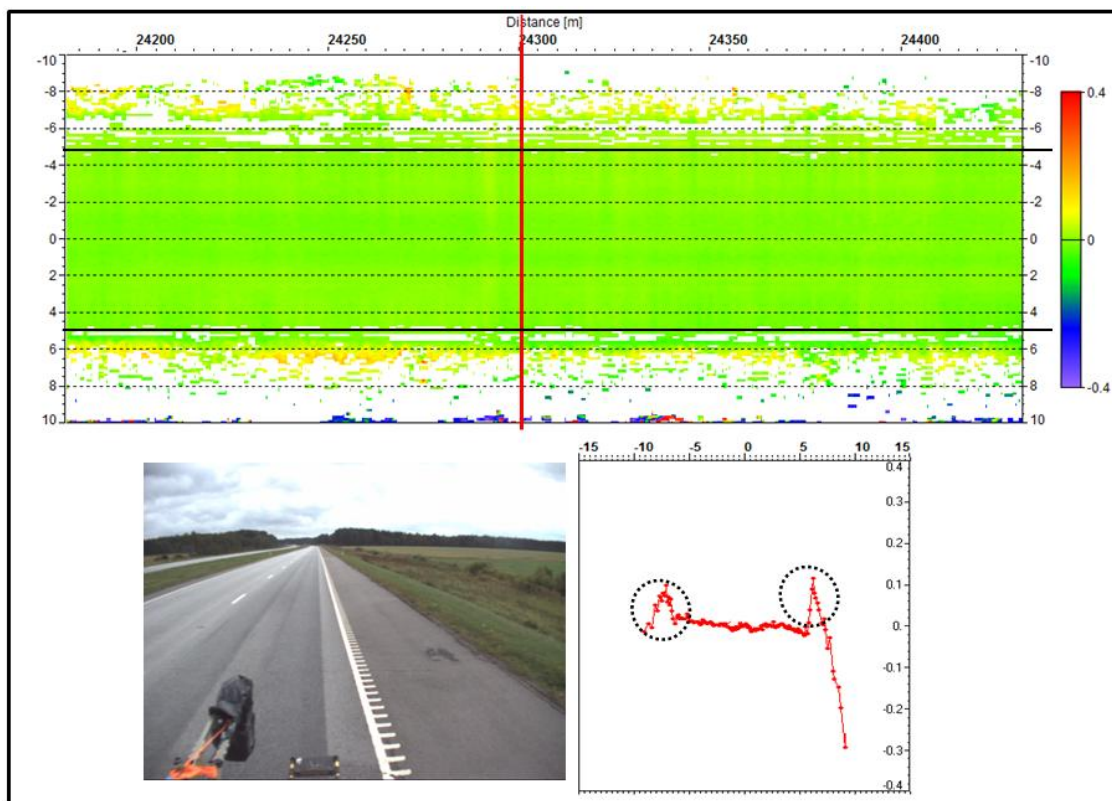


Figure 62_1. Laser scanner surface elevation map from section 2 (road 1). The still image and cross section profile is picked from chainage 24 300m. The black lines on surface map represent the approximated road edges.

6.2.4 Accelerometer

The road surface is generally in fairly good condition with small defects (Figure 62_2). Lane 1 has rut repairs on the whole section, and has generally a bit higher roughness than lane 2. Service lane has not been paved at the same time as the two driving lanes, and has generally higher roughness than the two driving lanes.

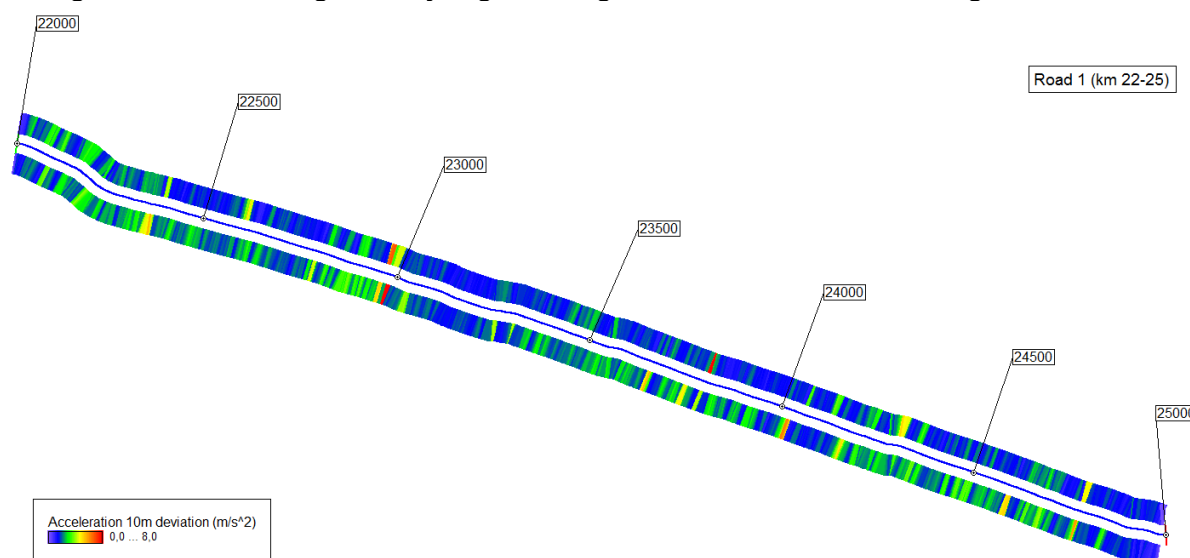


Figure 62_2: Acceleration 10m deviation from section 2 presented as a map.

There are some transverse cracks. Some of them have been patched. Most of the acceleration spikes in the section are caused by transverse cracks and their patches. Gravel and water on the edge of road also cause unevenness (Figure 62_3). The biggest spikes in 22 950-22 990m are caused by bridge joints.

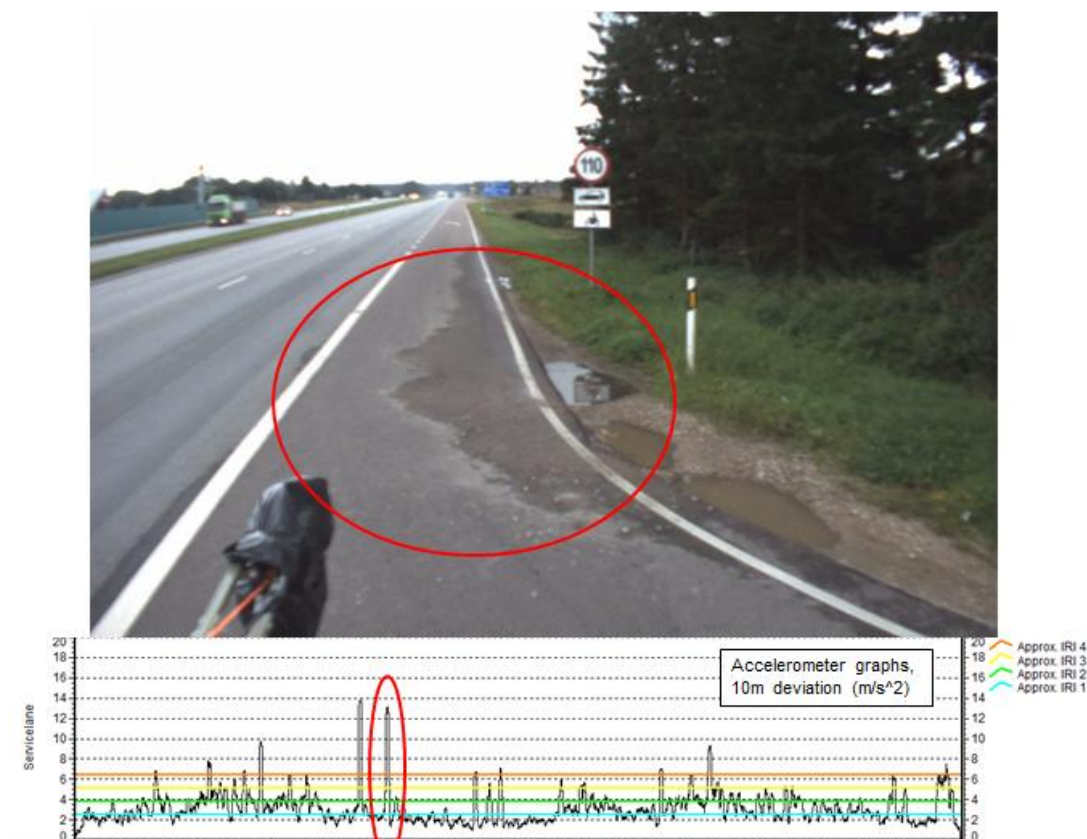


Figure 62_3. Deformations with standing water (service lane, 23040m)

6.2.5 Rutting

Rutting varies in this test section (Table 62_2 and Figure 62_4). Generally rutting is about 10 mm on most of the section, but there are places where rutting is almost 20 mm. In these places where rutting is high there are high verges at the side of the road, which could cause the higher rutting. Lane 1 has rut repairs on the whole section. Distance between rut bottoms indicates that rutting in lane 1 is caused mainly by heavy trucks and in lane 2 mainly because of studded tires (passenger cars).

Table 62_2. Statistical results of rutting from section 2.

	Lane 1	Lane 2
Left rutting aver. (mm)	10,7	10,8
Right rutting aver. (mm)	12,8	10,2
Max rutting (mm)	20,1	17,7
Aver. height of the ridge rut (mm)	12,8	11,3

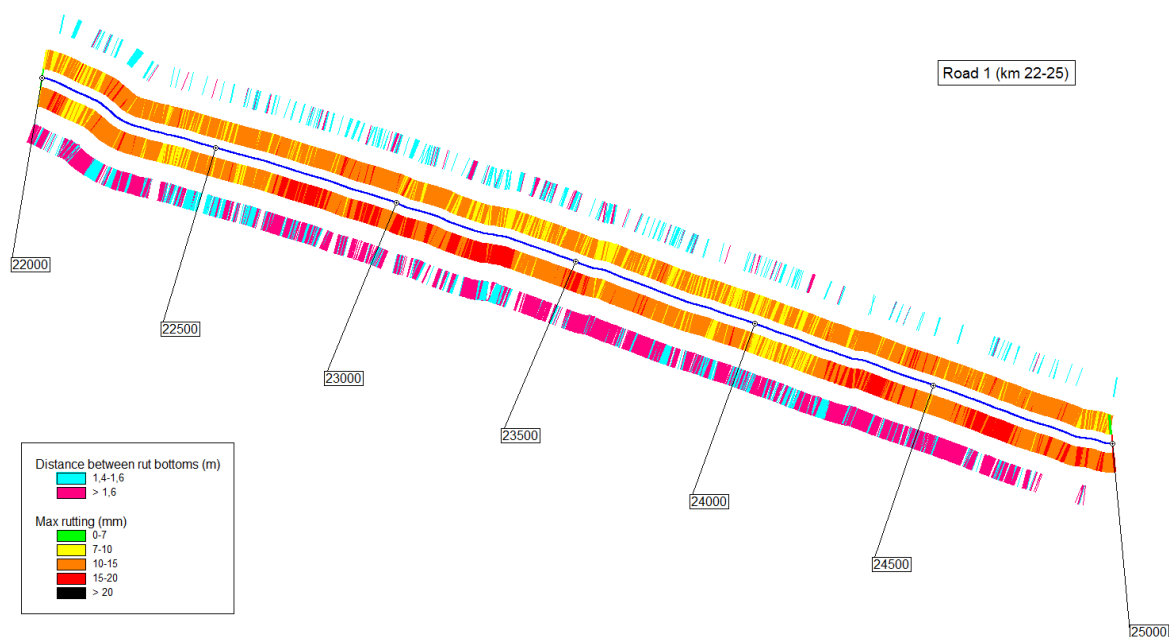


Figure 62_4. Maximum rutting in both lanes (inner lines, colours from green to black) together with distance between rut bottoms (outer lines, colours pink and blue).

6.3 Section 3 – Road 1 km 42 - 45

The road section 3, road 1 from km 42 to 45, has been rehabilitated in years 2005-2006. Road 1 goes from Tallinn to Narva. The rehabilitated section was from Maardu to Valgejõe and in this study the section Kuusalu - Vahastu was examined.

Road is in fairly good condition with small defects. A few small transverse cracks and some other pavement damage was detected. Drainage is in adequate condition, verges are present on both edges. Bridge at the end of section is in poor condition. Section 3 has deeper ruts in lane 1, especially in the left wheelpath. Ruts are located mainly between chainage 43 500 – 45 000m. The road section has been rehabilitated with simple structure; adding only new pavement layers.

6.3.1 Designed Structure

Table 63_1 presents the designed structures, which should have been implemented in the rehabilitation process. The information is based on detailed plans and other information provided by Riigikontroll. According to the design the road was only repaved with two layers of new pavement.

Table 63_1. The detailed design information from section 3.

Structures location in the survey area	41,5-44,5
Pole number	387+75...417+75
Length of structure type	3
Materials	Thickness [cm]
Crushed aggregate mastic asphalt KMA12	4
Dense Asphalt concrete TAB 16 II	5
Existing surface coverage	
Total thickness [cm]	9

6.3.2 GPR

Road rehabilitation design includes only new pavement. Layer thicknesses fulfill the design demands and even exceed it by 10 % almost through the whole section. The layer thicknesses between different measured lanes are at quite the same level, major differences were not detected. Detailed maps and statistics of layer thicknesses are presented in Appendix 3.

Around chainage 44 900 m a change in road structure was detected (Figure 63_1). It could possibly be related to the ramp.

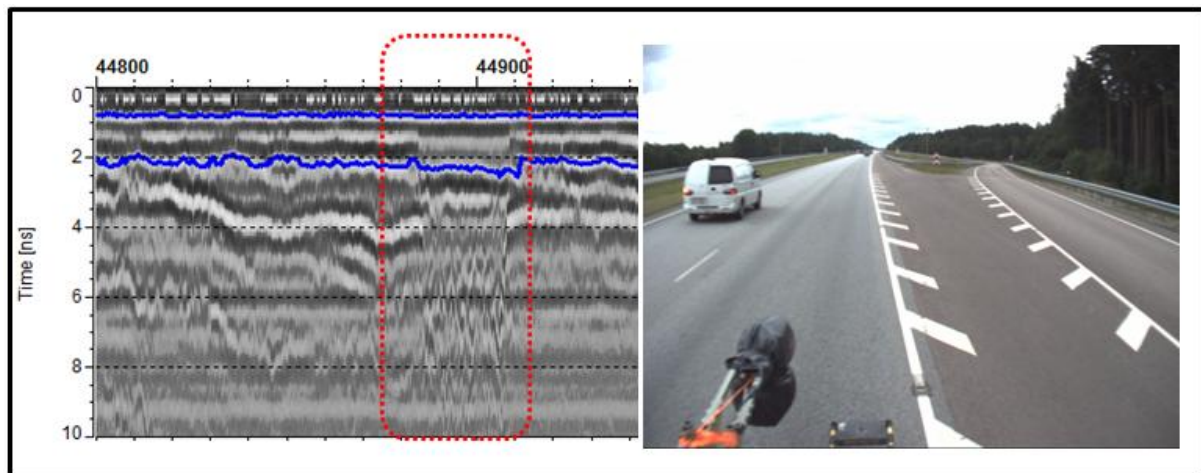


Figure 63_1. GPR data and still image from chainage 44 8970m.

6.3.3 Laser Scanner

As other measured and analysed sections from road 1, in this section the road surface was also quite even. In places slight verges are present.

6.3.4 Accelerometer

Generally the road surface is smooth with only small defects. Lane 1 has slightly higher general roughness than lane 2, but the difference is not great (Figure 63_2). Service lane has not been paved at the same time as the two driving lanes, and generally has higher roughness than the two driving lanes. The bridge at the end of the section is in very poor condition.

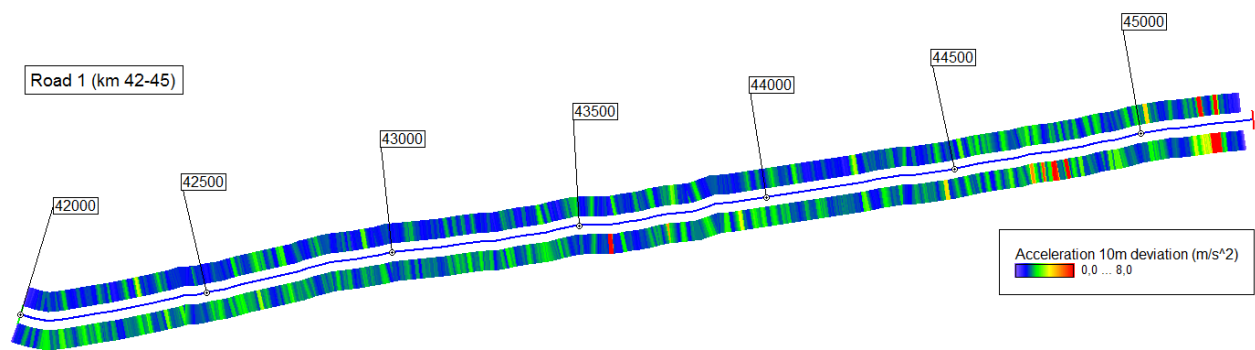


Figure 63_2: Acceleration 10m deviation from section 3 presented as a map.

There are a few small transverse cracks and some other pavement damage (Figures 63_3 and 63_4).

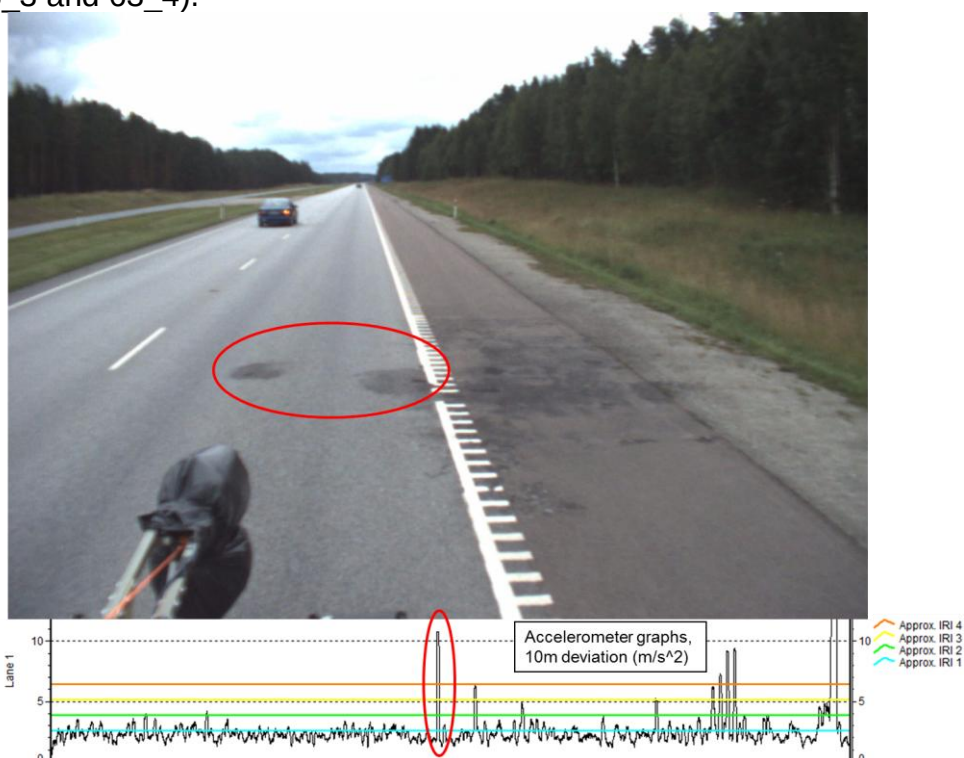


Figure 63_3. Pavement damage on lane 1 at chainage 43 550m. Perhaps this was caused by a recent crash.



Figure 63_4. Bump on road surface (related to frost?) in lane 1, at chainage 43 700m.

6.3.5 Rutting

Rutting is high in this section. It is especially high in lane 1 with the highest rutting found at the end of the section, from 43 600 m to 45 300 m. Distance between rut bottoms indicates that rutting on lane 1 is caused mainly because of studded tires (passenger cars). In lane 2 distances between rut bottoms is higher on most of the section as seen in the Figure 63_5, which indicates that it could be caused by heavy trucks.

Table 63_2. Statistical results of rutting from section 3.

	Lane 1	Lane 2
Left rutting aver. (mm)	17,3	11,9
Right rutting aver. (mm)	14,2	12,7
Max rutting (mm)	30,5	36,0
Aver. height of the ridge rut (mm)	21,2	14,0

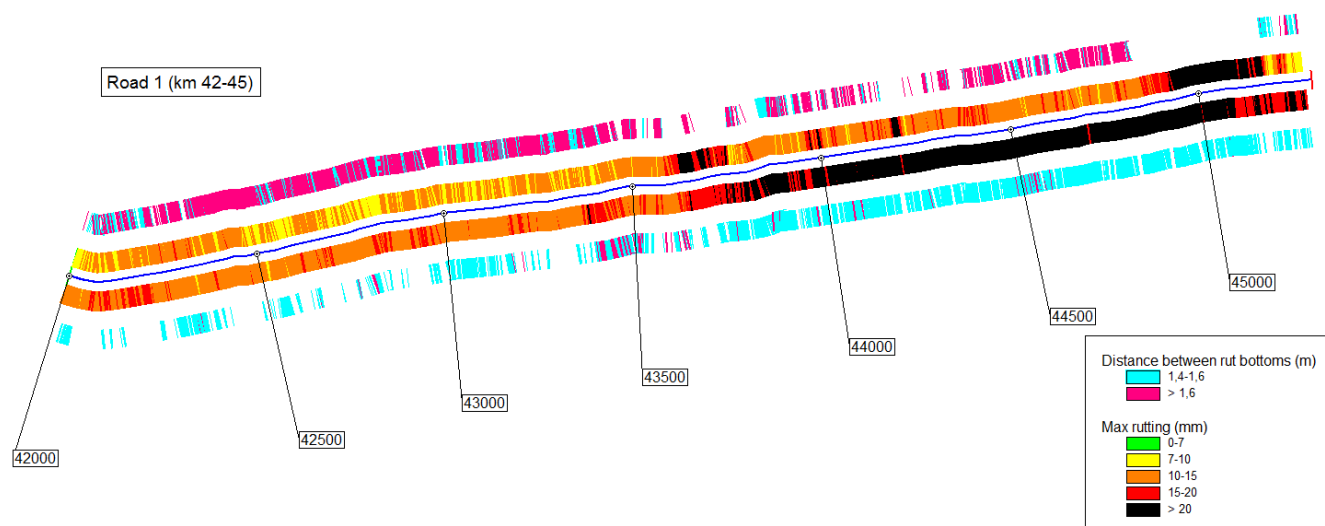


Figure 63_5. Maximum rutting in both lanes (inner lines, colours from green to black) together with distance between rut bottoms (outer lines, colours pink and blue).

6.4 Section 4 – Road 3 km 82-85

Road section 4, road 3 from km 82 to 85, has been rehabilitated in years 2005-2007. Road 3 goes from Jõhvi to Tartu and further to Valga. The rehabilitated section was from Raja to Kääpa and in this study the section Metsaküla – Ruskavere was examined.

The road is in fairly good condition with small defects. A few small transverse cracks and some other pavement damage was detected. Drainage is in adequate condition, though poor in some short sections because the ditches have a lot of vegetation. Small verges are locally present. The road section has been rehabilitated only with a simple structure; adding only new pavement layers and stabilisation.

6.4.1 Designed Structure

Table 64_1 presents the designed structures, which should have been implemented in the rehabilitation process. The information is based on detailed plans and other information provided by Riigikontroll. The designed structure consists of two pavement layers and a stabilization layer.

Table 64_1. The detailed design information from section 4.

Structures location in the survey area	82-85
Pole number	820+00...850+00
Length of structure type	0
Materials	Thickness [cm]
TAB 12 I	4
PAB 16	5
Complex stabilization KS 32	15
Total thickness [cm]	24

6.4.2 GPR

Layer thicknesses are close to planned thicknesses or over them. Around the bridge at 83 150 m the layer thickness doesn't fulfill the planned structure. In this road section the PAB 16 layer is thinner in lane 1 than in lane 2. Maps and statistics of interpreted layer thicknesses are shown in Appendix 4.

Cross section profile from chainage 84 shows that the road has most likely been widened (Figure 64_1). Longitudinal profiles show that around the bridge from 82980m to 83340m the road structure is different than elsewhere (Figure 64_2).

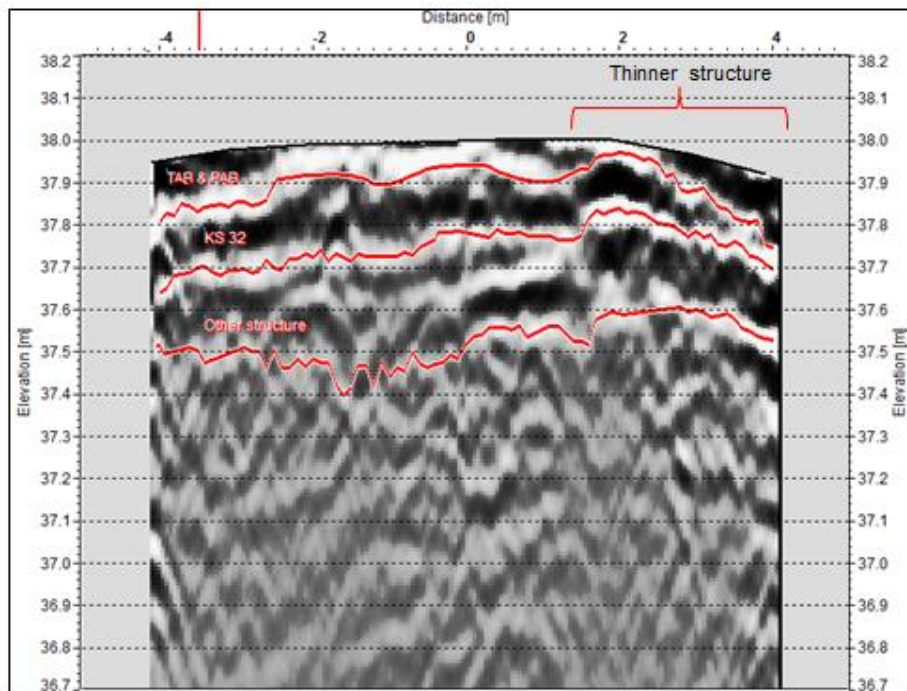


Figure 64_1. GPR data of cross section at chainage 84 shows that the road has probably been widened. The total thickness of road structure is thinner on the right side, but instead the bound pavement layers are thicker.

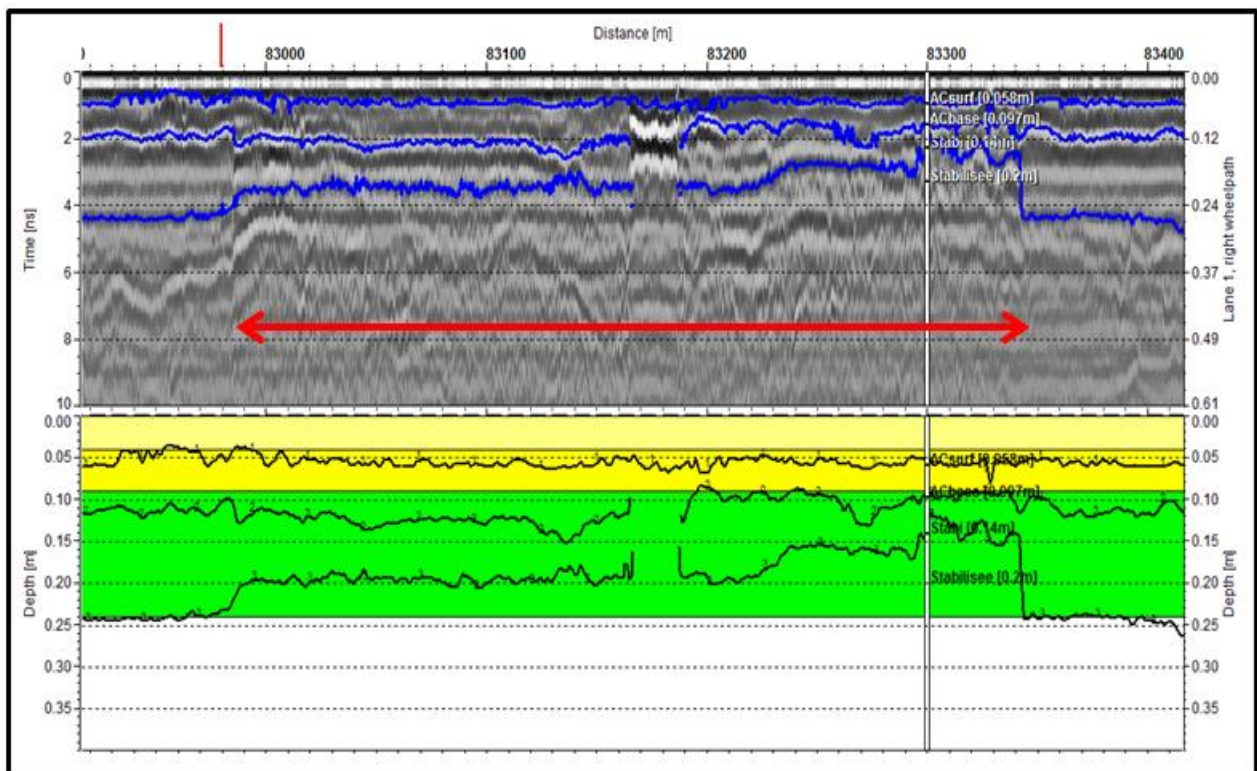


Figure 64_2. GPR data as longitudinal profile. The area where structure is different around the bridge has been marked with red arrow.

6.4.3 Laser Scanner

In general road shape is in good condition, minor verges were detected locally (Figure 64_3). Laser scanner rainbow map showed that road section has good crown section; two sided cross fall (Figure 64_4).

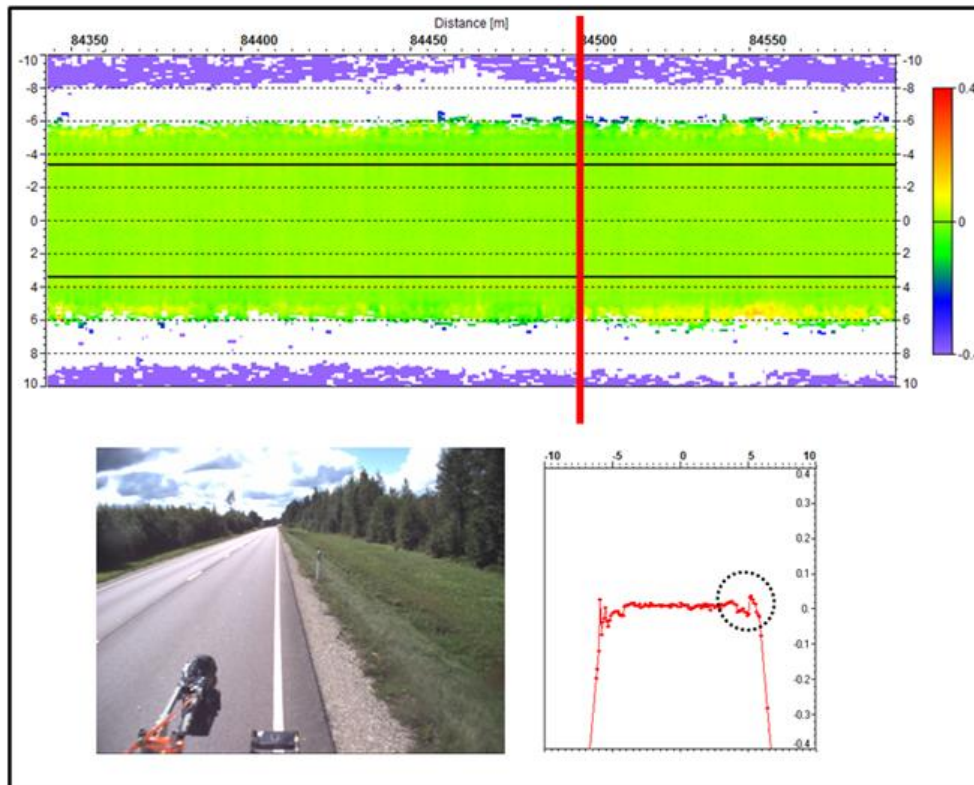


Figure 64_3. Laser scanner surface elevation map from section 4 (road 3). The still image and cross section profile is picked from chainage 84 495m. The black lines on surface map represent the approximated road edges.

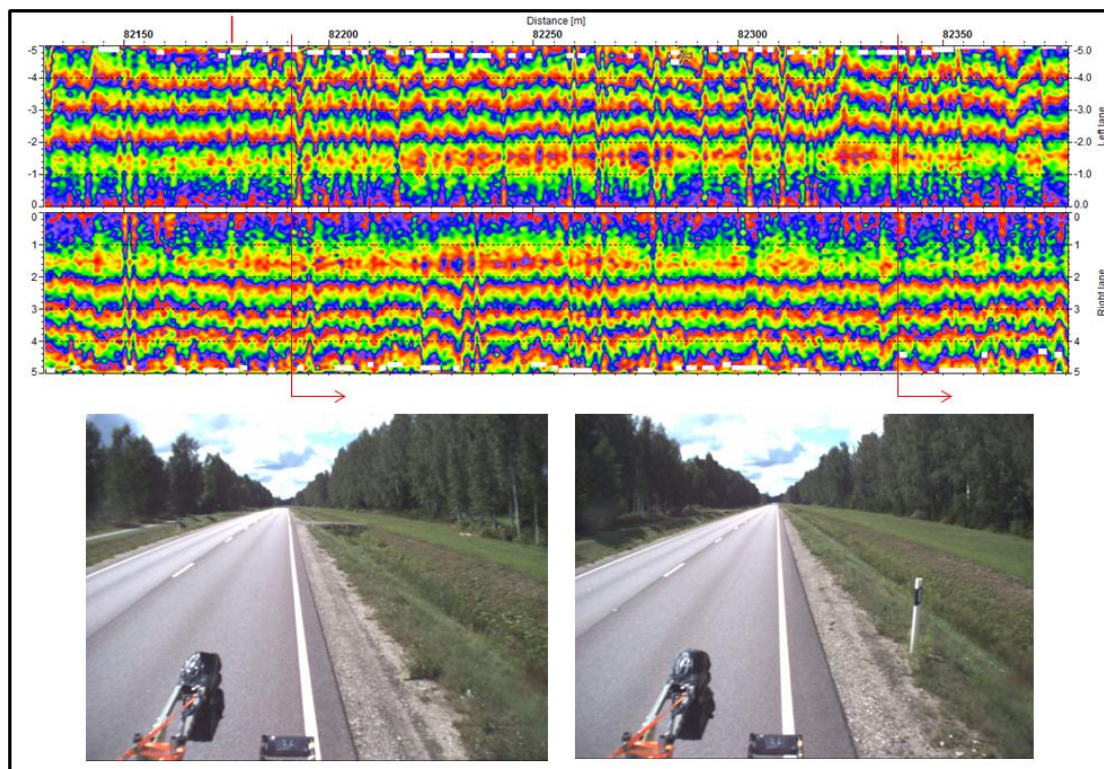


Figure 64_4. Laser scanner rainbow map from section 4 (road 3) from 82 130m to 82 380m. Each complete colour palette represents 30mm change in surface level relative to the centerline.

Generally the road surface is in fairly good condition with some small defects (Figure 64_5). There are some transverse and longitudinal cracks and the biggest acceleration spikes are caused by these cracks (and bridge joints in 83150-83185m) (Figure 64_6).



6.4.5 Rutting

Rutting is generally low in the section. Average rutting for both lanes is less than 10 mm (Table 64_2). In places rutting is between 10 and 15 mm (Figure 64_7).

Table 64_2. Statistical results of rutting from section 4.

	Lane 1	Lane 2
Left rutting aver. (mm)	9,5	9,1
Right rutting aver. (mm)	8,6	8,9
Max rutting (mm)	15,7	15,8
Aver. height of the ridge rut (mm)	10,8	10,8

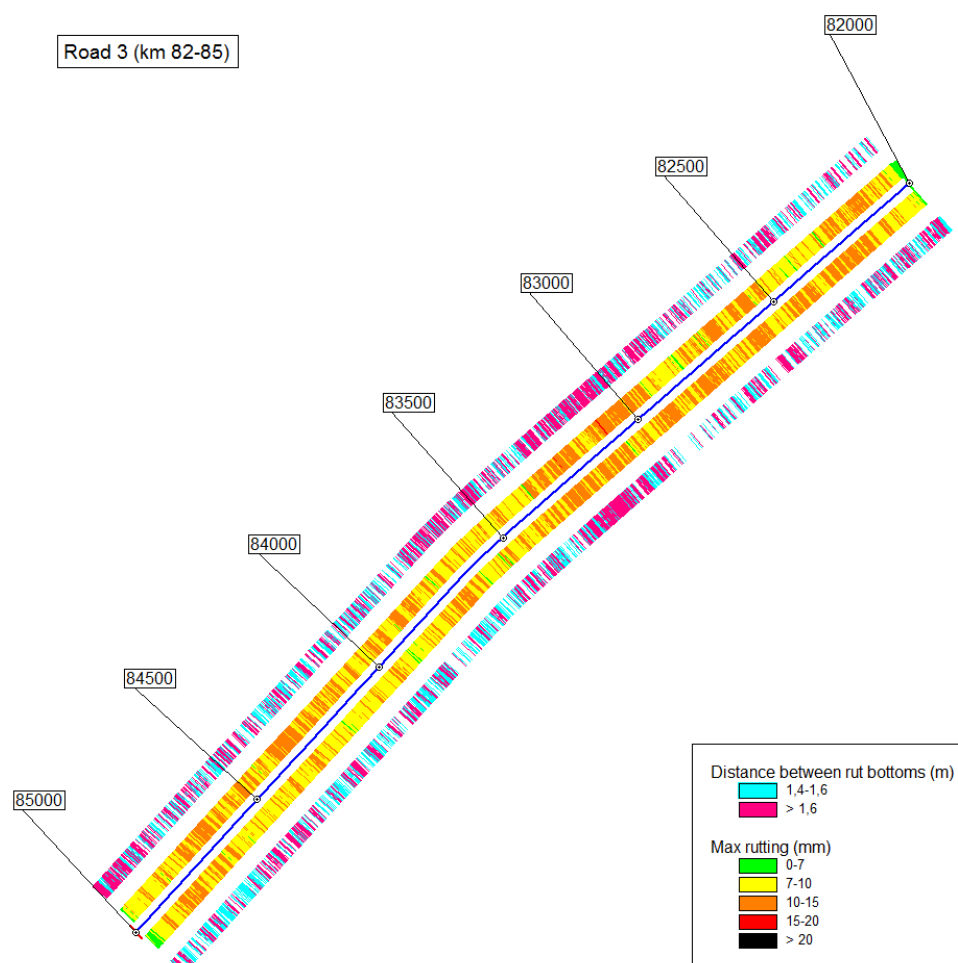


Figure 64_7. Maximum rutting in both lanes (inner lines, colours from green to black) together with distance between rut bottoms (outer lines, colours pink and blue).

6.5 Section 5 – Road 3 km 198-201

The road section 5, road 3 from km 198 to 201, has been rehabilitated in years 2005-2007. Road 3 goes from Jõhvi to Tartu and further to Valga. The rehabilitated section was from Anetmäe to Valga and in this study the section Rõngu – Jaanikese was examined.

Road is in quite poor condition and has lots of damages and patches. Drainage is also in poor condition. The road lies mainly on a flat area and the ditches are full of vegetation. Reasons for damages could be that the old poor quality bound layer has been left in the structure, poor drainage, varying total thickness of road structure (mainly 0,5-1m) and subgrade quality (clay according to coring). The road section has been rehabilitated with a simple structure; adding only new pavement layers and stabilisation.

6.5.1 Designed Structure

Table 65_1 presents the designed structures, based on detailed plans and other information received from Riigikontroll. The designed structure consists of two pavement layers and a stabilisation layer.

Table 65_1. The detailed design information from section 5.

Structures location in the survey area	198-201
Pole number	207+00...237+00
Length of structure type	3
Materials	Thickness [cm]
Dense fine grained asphalt concrete TAB 12 I	4
Porous asphalt concrete PAB 16	5
Complex stabilisation layer KS 32	15
Existing gravely soil base and embankment	12-180
Total thickness [cm]	36-204

6.5.2 GPR

Pavement fulfills the planned structure, but in many places stabilisation layer is found to be thinner than it should be according to plan. Especially in longitudinal direction the thickness of KS 32 layer varies. The KS 32 layer is more than 10 % under planned in 21-47 % of distance and average undershoot is about 3-4 cm. Detailed maps and statistics of interpreted layer thicknesses are shown in Appendix 5.

6.5.3 Laser Scanner

From laser scanner data it was observed that in places road is located in a really flat area, in the middle of a field area (Figure 65_1). Road cross fall is excellent crown section.

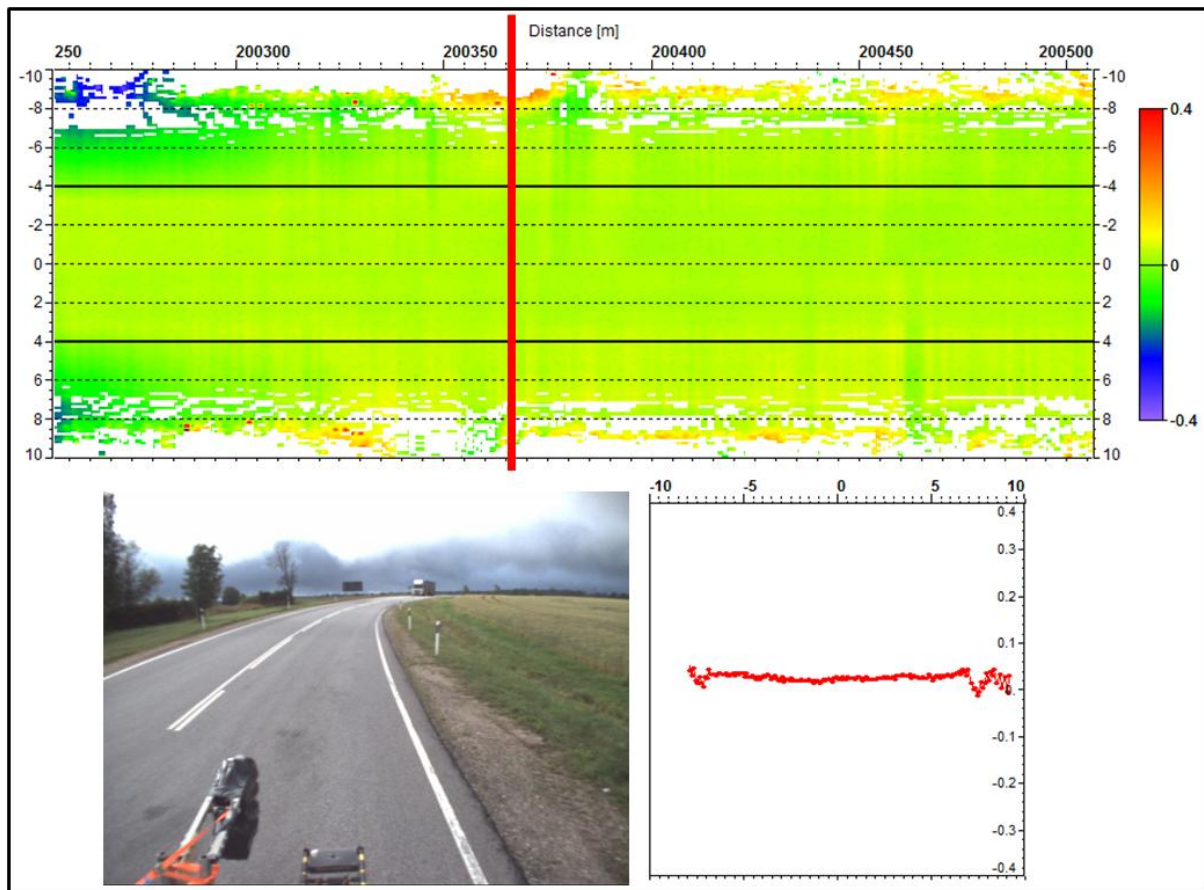


Figure 65_1. Laser scanner surface elevation map from section 5 (road 3). The still image and cross section profile is picked from chainage 200 360m. The black lines on the surface map represent the approximated road edges.

6.5.4 Accelerometer

The pavement in this road section is not in good condition and has a lot of patches (Figure 65_3). These patches cause high acceleration values that can be seen with red color on the map presentation (Figure 65_2). All of the bigger spikes in the acceleration graphs are caused by the patches.



Figure 65_2: Acceleration 10m deviation from section 5 presented as a map.

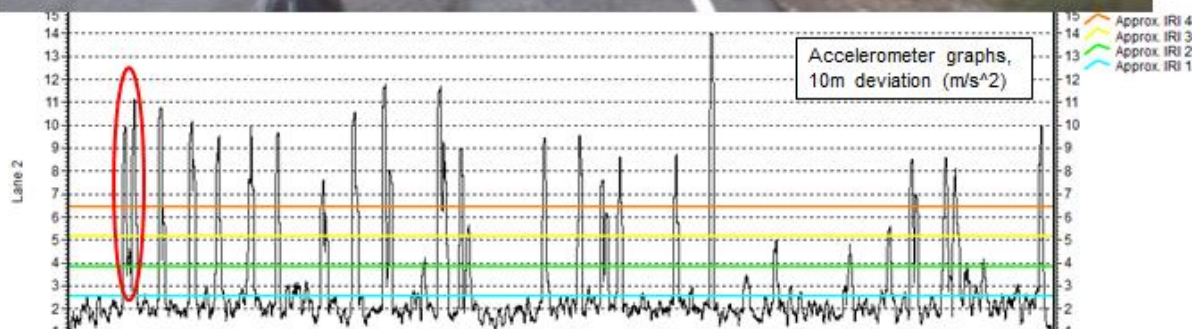


Figure 65_3. The patches are seen on both lanes. The photo is from lane 1 at chainage 198 180m.

6.5.5 Rutting

Rutting is quite low in the section, thanks to patching. Average rutting is 8-10 mm. Lane 1 has slightly higher average rutting than lane 2. In places rutting is between 10-15 mm and maximum rutting is about 17-18 mm on both lanes.

Table 65_2. Statistical results of rutting from section 5.

	Lane 1	Lane 2
Left rutting aver. (mm)	9,6	8,3
Right rutting aver. (mm)	8,3	8,0
Max rutting (mm)	16,7	17,9
Aver. height of the ridge rut (mm)	9,9	9,1



Figure 65_4. Maximum rutting in both lanes (inner lines, colours from green to black) together with distance between rut bottoms (outer lines, colours pink and blue).

6.6 Section 6 – Road 2 km 150-153

The road section 6, road 2 from km 150 to 153, has been rehabilitated in years 2005-2007. Road 2 goes from Tallinn to Tartu, to Võru and further to Luhamaa. In this research the section Puurmani – Kärevere was examined.

This section was the most complex and problematic to be analysed and certain assumptions had to be made when analysing and reporting the results.

The pavement in the road section is in poor condition and has a lot of patches and cracks. Drainage is in poor condition. The road lies mainly on flat landscape and the ditches are full of vegetation and. According to drill core, the thick tarmac (mustkate) layer has been covered with new pavement layers, which is not considered to be a good solution because bound layers are too thick. Reasons for damages could be that tarmac layer has been covered with new pavement, poor drainage, variable total thickness of road structure (damages appear especially where there is thin total thickness) and poor quality materials (the subgrade is sand, so the frost cannot be a problem). The road section has been rehabilitated only with a new bound base and wearing course overlay.

6.6.1 Designed Structure

Designed structures are presented in Table 66_1. The information is based on detailed plans and other information provided by Riigikontroll. The designed structure consists of three different layers; stone mastics asphalt (3,5cm), porous asphalt concrete (5cm) and precoated chippings (6cm).

Table 66_1. The detailed design information from section 6.

Structures location in the survey area	150-153
Pole number	5+00...35+00
Length of structure type	3
Materials	Thickness [cm]
Stone mastic asphalt KMA 12 (Top layer of pavement)	3.5
Porous asphalt concrete PAB 16 (Base layer of pavement)	5
Precoated chippings MUK 16/32 (Basis layer)	6
remained asphalt concrete	11-31
Existing gravelly soil base and embankment	
total thickness [cm]	25,5-45,5

6.6.2 GPR

From the GPR data interpretation two layer surfaces have been interpreted. The interface between KMA12 and PAB16 is not visible, because their electromagnetic properties (dielectric values) are very close to each other. The first interpreted layer surface is the lower surface of pavement layer (KMA 12 & PAB 16). Other layer

surface is probably not MUK 16/32, because this layer was not found in drill core (Figure 66_1). This layer surface is maybe the leveling course and it seems to be continuous throughout the section. Pavement thickness is more than 10 % thinner through almost the entire section. Average undershoot is between 1,7-2,0 cm. Maps and statistics of interpreted layer thicknesses are shown in Appendix 6.

According to drill core data (Figure 66_1) it is doubtful that the road actually has the precoated chippings MUK 16/32. Instead the road structure has 2cm “tasanduskiht” and below that 0,6cm “pindamiskiht” (Figure 66_2). The total thickness of road structure is variable, example in Figure 66_3.

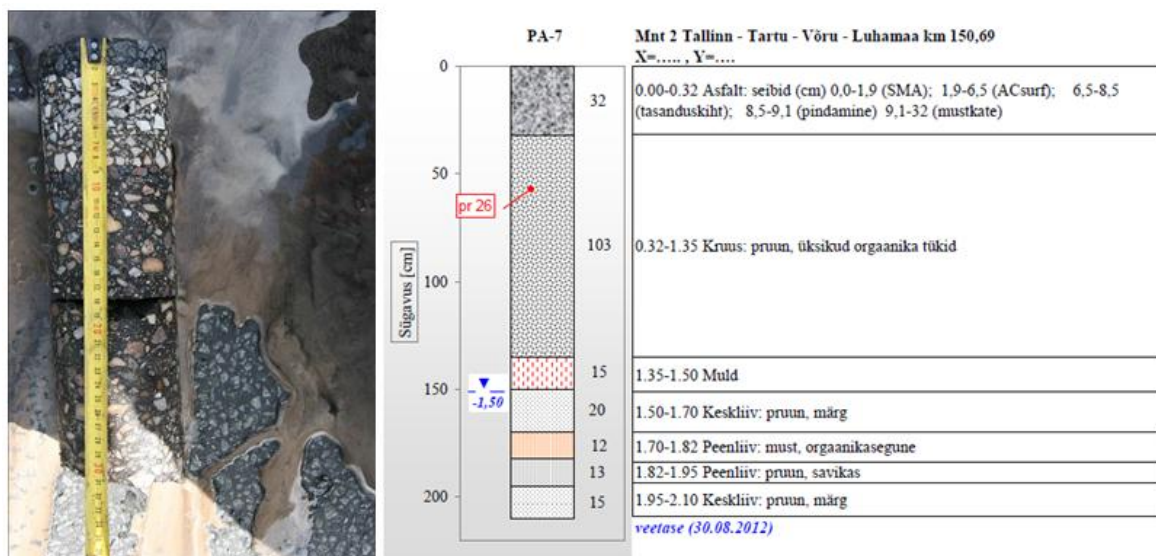


Figure 66_1. The photo (left) and layer thicknesses of drill core.

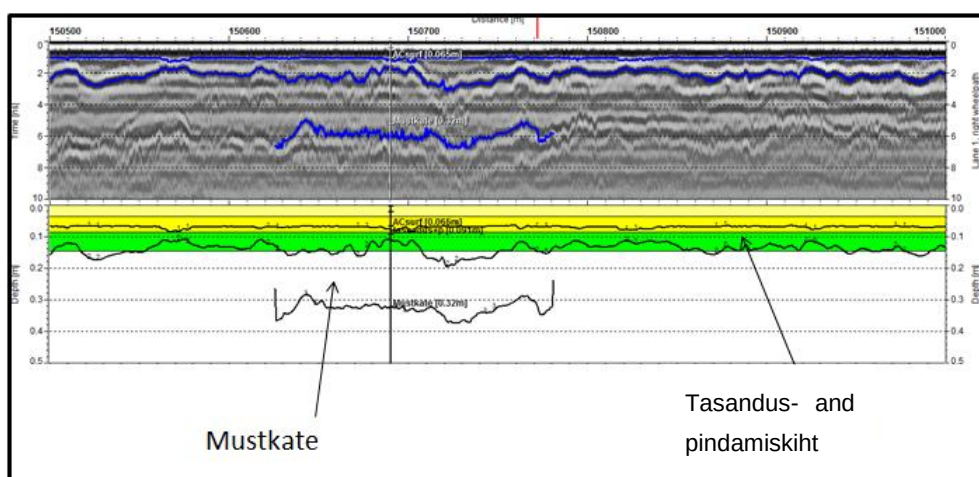


Figure 66_2. Yellow areas presents the KMA and PAB layers, green area should be stabilisation layers, but it seems that below the pavement is “tasandus- and pindamiskiht”. As an example short sections of lower surface of mustkate has been interpreted in the middle of figure.

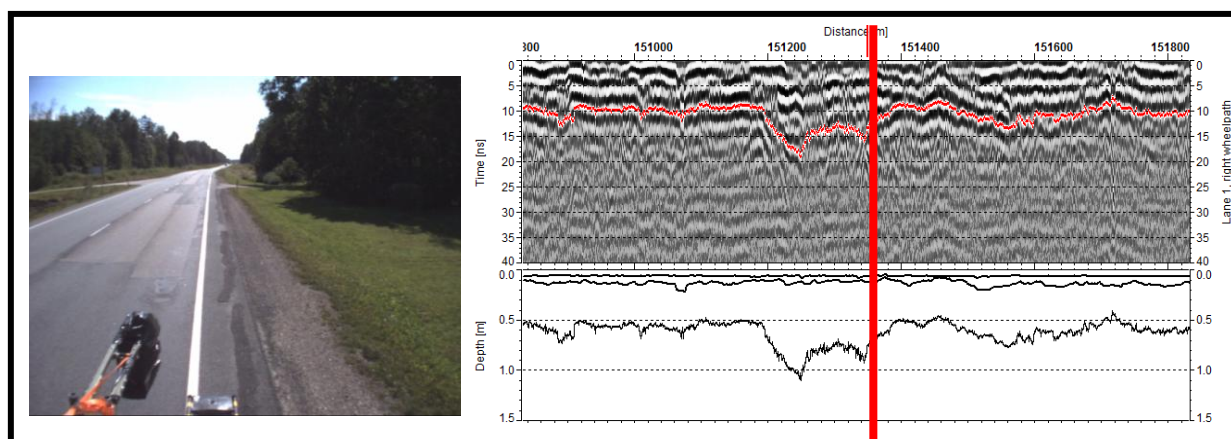


Figure 66_3. The total structure thickness is quite varying. Red line on the GPR profile shows the example chainage where layer thickness changes from thick to thin. Still image is from the same chainage.

According to GPR cross section profile from chainage km 152, road has been widened on the left side (Figure 66_4). Widened structures seem to be like steps. This “Step structure” is a good structural solution to prevent reflection cracking.

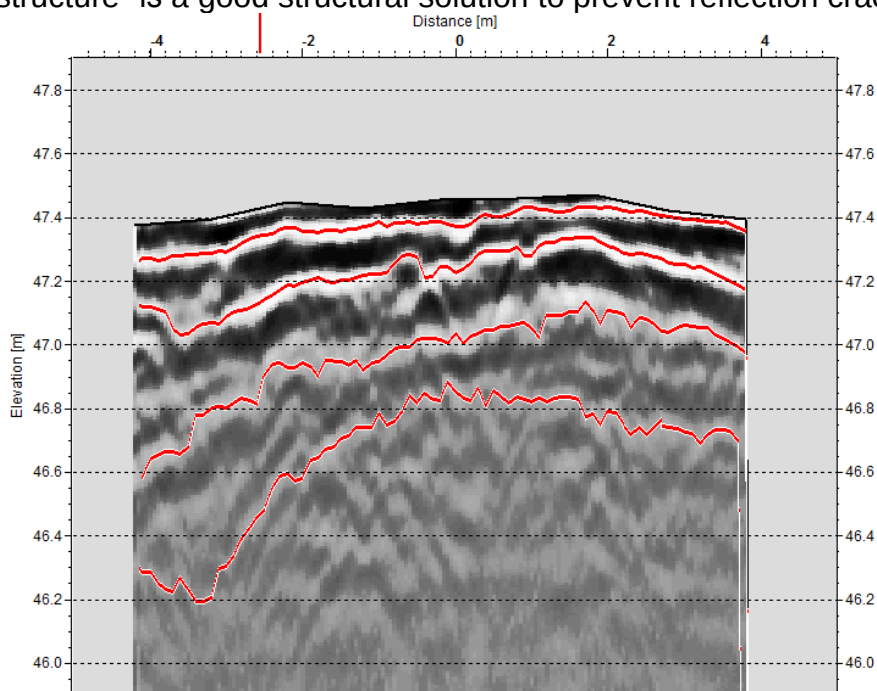


Figure 66_4. GPR cross section from chainage km 152.

6.6.3 Laser Scanner

Laser scanner data shows that road has quite deep ruts. Ruts are seen both in the surface elevation map and in cross sections (Figure 66_5). From the rainbow maps it can be seen that the changes in road surface are in the same locations as access roads (Figure 66_6). In earlier studies, in the context of the ROADEX projects for example, it was noticed that the culverts of access roads are one of the most critical

parts of a road drainage system. The culverts often have problems; they can be totally missing, clogged or installed faultily. The inadequate culverts cause further problems like deformations in the road surface and frost heave problems.

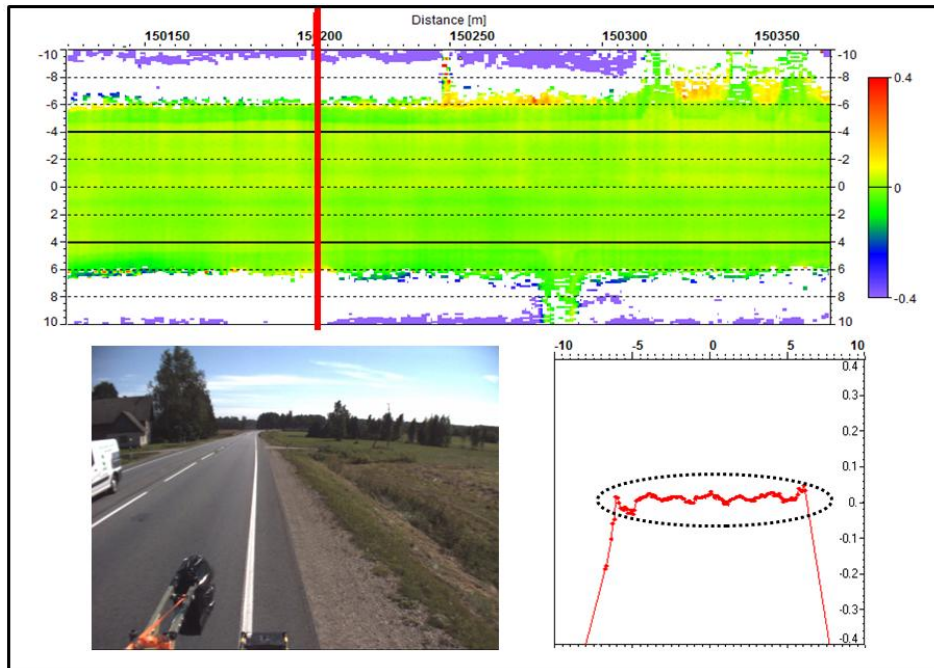


Figure 66_5. Laser scanner surface elevation map from section 6 (road 2). The still image and cross section profile is picked from chainage 150 250m. The black lines on surface map represent the approximated road edges. A black dashed line is used to indicate the location of ruts observed on the road surface.

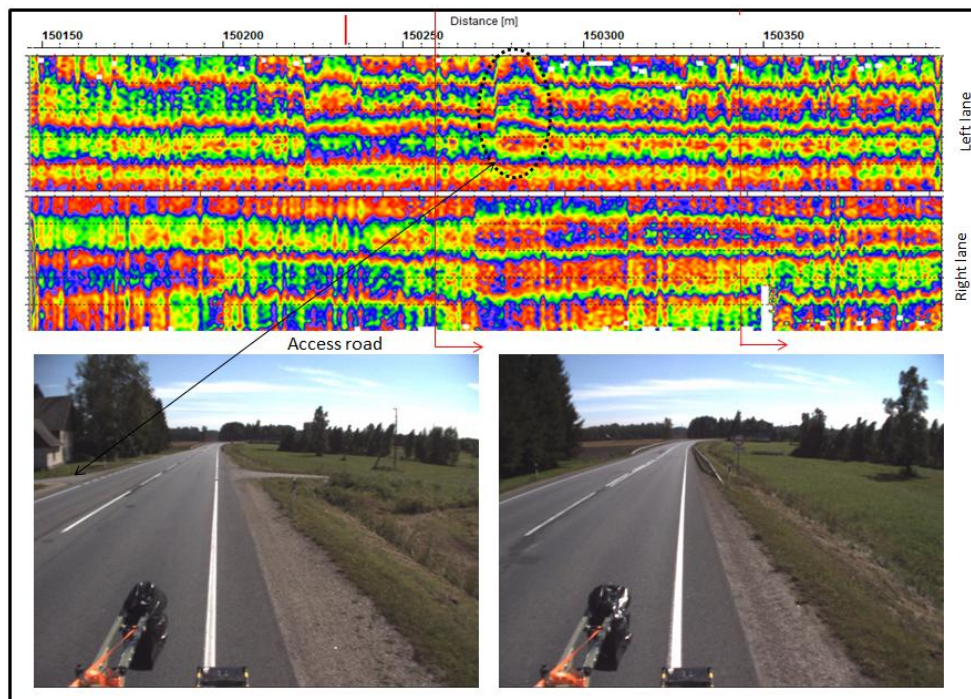


Figure 66_6. Laser scanner rainbow map from section 6 (road 2) from 150 150m to 150 400m. Each complete color palette represents 30mm change in surface level relative to the centerline. The access road and the deviation it has caused in the road surface has been marked in the figure.

6.6.4 Accelerometer

The pavement in this road section is not in good condition and has a lot of patches and transverse cracks that have been patched. These patches and transverse cracks are the cause of the high roughness in the section. Lane 1 has higher roughness and more patches than lane 2 (Figure 66_7).



Figure 66_7. Acceleration 10m deviation from section 6 presented as a map.

Figure 66_8 shows a place (about 151 400 m) where a lot of damages and patching are visible and roughness is high. In this location the layer thickness changed from thick to thin and there is also a high verge beside the road. Possibly access road (seen in the Figure 66_8) culverts could also be the cause of this high roughness.

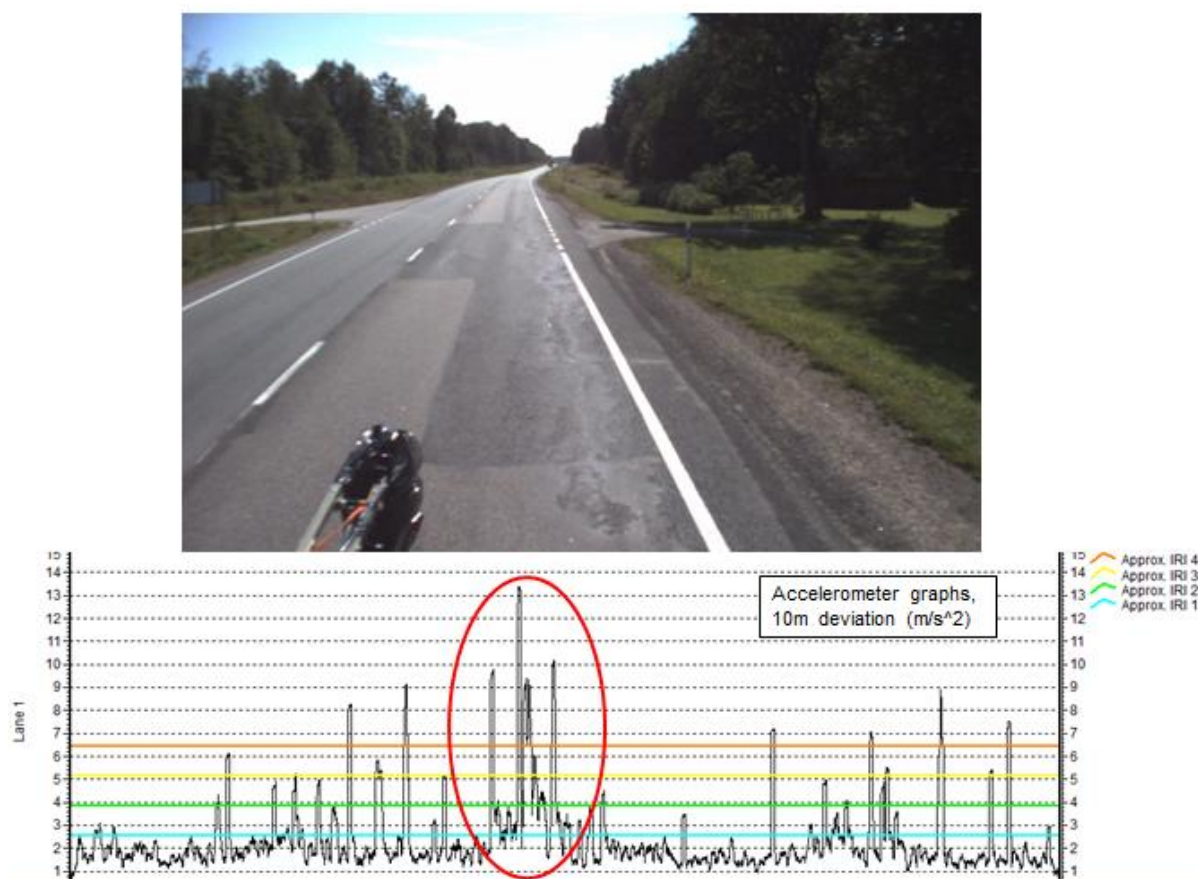


Figure 66_8. Damages and patches that cause high roughness (151 400 m).

6.6.5 Rutting

Rutting is high in the road section. Maximum rutting is over 20 mm in almost the entire section in the lane 1 (Table 66_2). Lane 2 also has high rutting, but slightly lower than lane 1. Distance between rut bottoms indicates that rutting in lane 1 is caused mostly by heavy trucks and in lane 2 by studded tires (passenger cars), Figure 66_9.

Table 66_2. Statistical results of rutting from section 6.

	Lane 1	Lane 2
Left rutting aver. (mm)	21,3	13,8
Right rutting aver. (mm)	18,9	19,5
Max rutting (mm)	32,8	34,0
Aver. height of the ridge rut (mm)	20,5	18,1

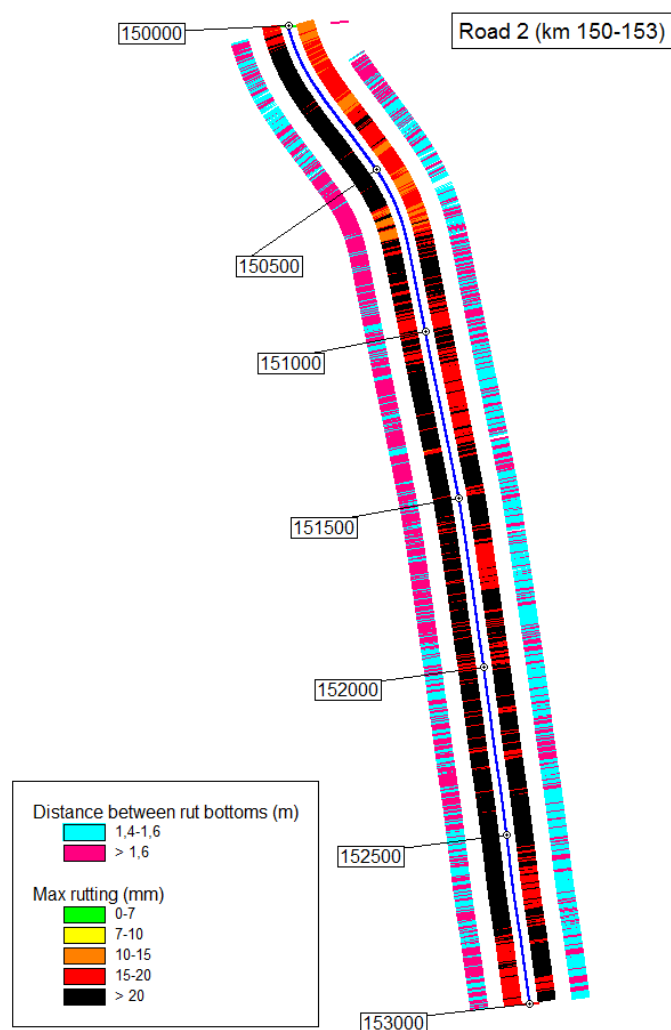


Figure 66_9: Maximum rutting in both lanes (inner lines, colours from green to black) together with distance between rut bottoms (outer lines, colours pink and blue).

6.7 Section 7 – Road 4 km 58-61

Road section 7, road 4 from km 58 to 61, was rehabilitated in years 2001-2002. Road 4 goes from Tallinn to Pärnu and further to Ikla. The section between Vaimõisa and Konuvere was examined in this research.

The pavement is in fairly good condition with some small defects like cracks. Damage is mainly located at the 0-level and in roadcuts (definitions in Appendix 12). Drainage condition varies from good to poor. The interpreted layer thicknesses are either too thin or too thick. The road section has been partially repaved lately. The stabilisation layer has been partly damaged. Stabilisation has possibly failed because the interface between new and old bound layer cannot be seen in the drill core sample. Reason for damages could be related to frost problems accompanied by too thin a total structure thickness. The road section has been rehabilitated only with a new bound base and wearing course overlay. From this section one drill core sample from stabilized course was analysed in laboratory to find out the bitumen content. The sample was from chainage 58,8km and the bitumen content was 5,0%, which is

slightly higher than normally in stabilized base course and close to bitumen content of asphalt.

6.7.1 Designed Structure

Designed structures are presented in Table 67_1. The information is based on detailed plans and other information provided by Riigikontroll. The designed structure consists of two pavement layers and a stabilization layer.

Table 67_1. The detailed design information from section 7.

Materials	Thickness [cm]
Dense Asphalt concrete TAB 12I	4
Porous Asphalt concrete PAB 16 A	6
Bitumen stabilisation mix BS 32	15
Remained old asphalt pavement	12-32
Gravel or gravely sand	
sand	
Total thickness [cm]	37-67

6.7.2 GPR

Layer thicknesses are variable both in longitudinal and in transverse direction. This variation can be seen in the layer thickness maps (a lot of red and blue, but little green). The pavement layers are thinnest in lane 1, right wheelpath and middle. Stabilisation layer is at its thinnest in the beginning of the section. Maps and statistics of interpreted layer thicknesses are shown in Appendix 7.

Figure 67_1 presents the GPR cross section data from chainage 60, which shows that the total structure thickness is at the thinnest in the middle of road.

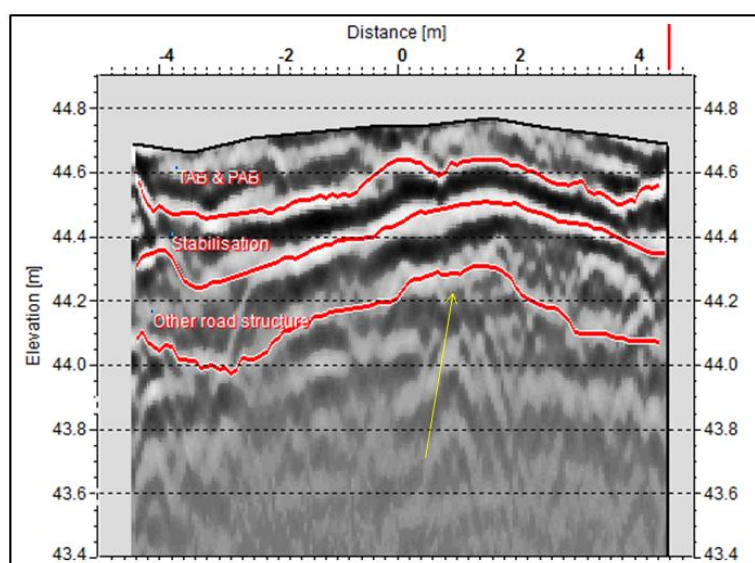


Figure 67_1. The GPR cross-section from chainage 60km. Yellow arrow shows the location of the thinnest structures.

6.7.3 Laser Scanner

Laser scanner data detected the deformations in the road surface and its slopes. Road surface has ruts and inner slopes have bulged in places (Appendix 7). As in the previous section, the problems possibly caused by access roads are also seen in the rainbow map (Figure 67_2).

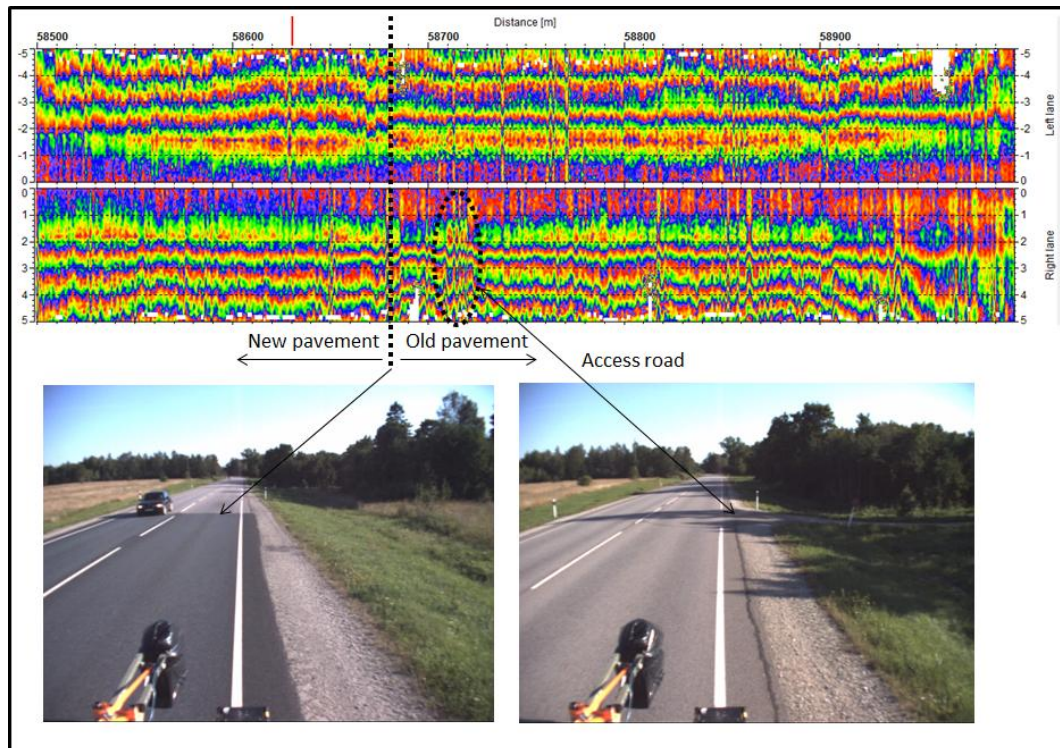


Figure 67_2. Laser scanner rainbow map from section 7 (road 4) from 58 500 to 59 000 m. Each complete color palette represents 30mm change in surface level relative to the centerline. The access road and the deviation it has caused in the road surface have been marked in the figure. The beginning of this section has been repaved recently and it is clearly seen that the new pavement is more even than the old pavement.

6.7.4 Accelerometer

The pavement is in fairly good condition with some small defects. Generally lane 1 has slightly higher roughness than lane 2, but both lanes have low general roughness (Figure 67_3). The older pavement between 58660 m and 59790 m has higher roughness than the other road section and some damage (Figure 67_4).

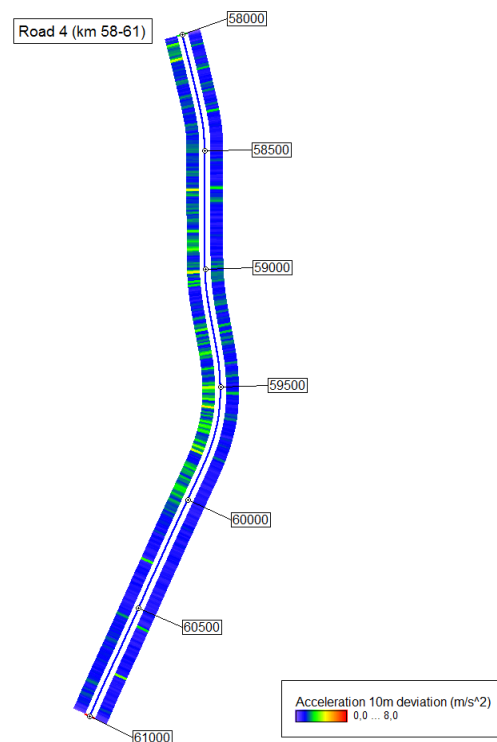


Figure 67_3. Acceleration 10m deviation from section 7 presented as a map.

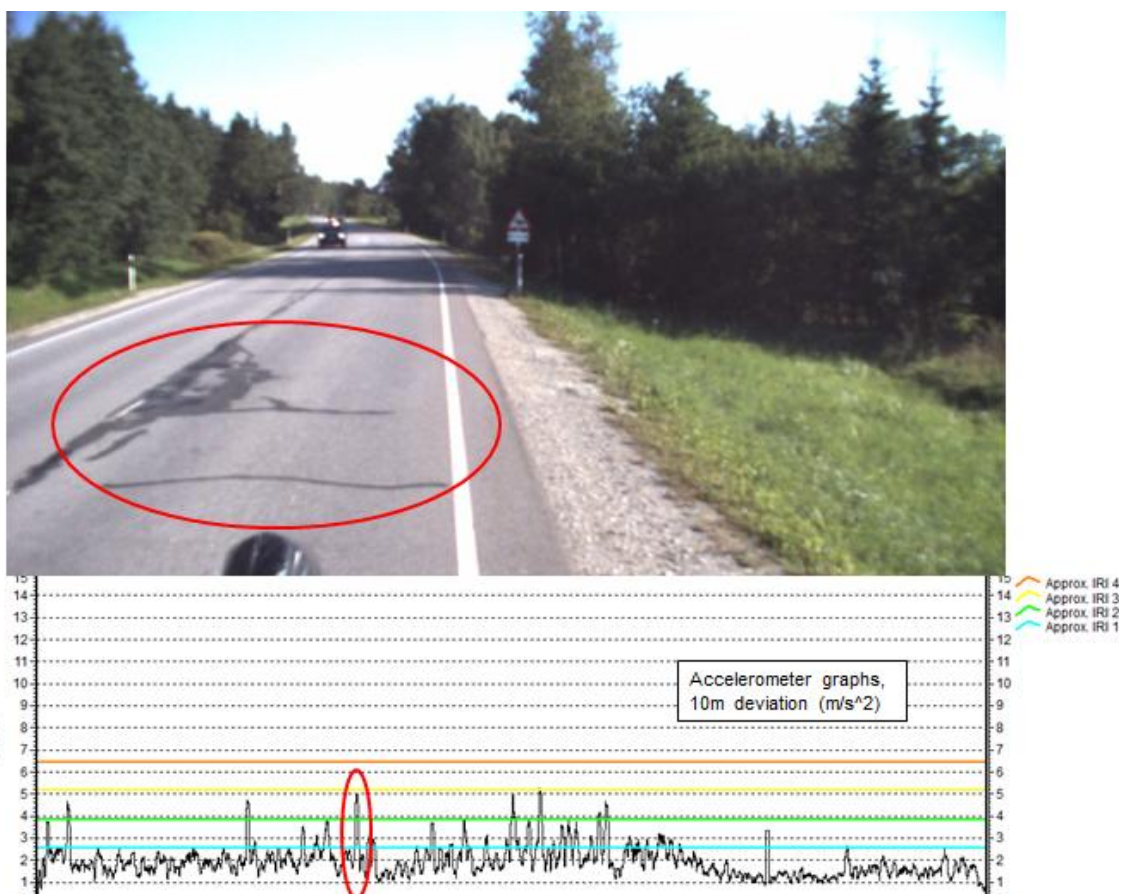


Figure 67_4. Cracking in lane 1 at chainage 59 010m.

6.7.5 Rutting

Rutting varies in the road section. The new pavement at the beginning of the section until about 58660 m has low rutting. The old pavement between 58660 m and 59790 m has 10-20 mm rutting. After 59790 m rutting is mostly between 10-15 mm. Especially at the end of the road section (after 59790 m) and in lane 1 the distance between rut bottoms indicates that rutting was caused by heavy trucks. In that part of the road section and especially in lane 1, the pavement thickness was found to be the thinnest. Rutting statistics from this road section are shown in Table 67_2 and rutting is presented on the map in Figure 67_5.

Table 67_2. Statistical results of rutting from section 7.

	Lane 1	Lane 2
Left rutting aver. (mm)	10,7	9,5
Right rutting aver. (mm)	11,3	11,0
Max rutting (mm)	19,6	30,3
Aver. height of the ridge rut (mm)	11,6	11,9

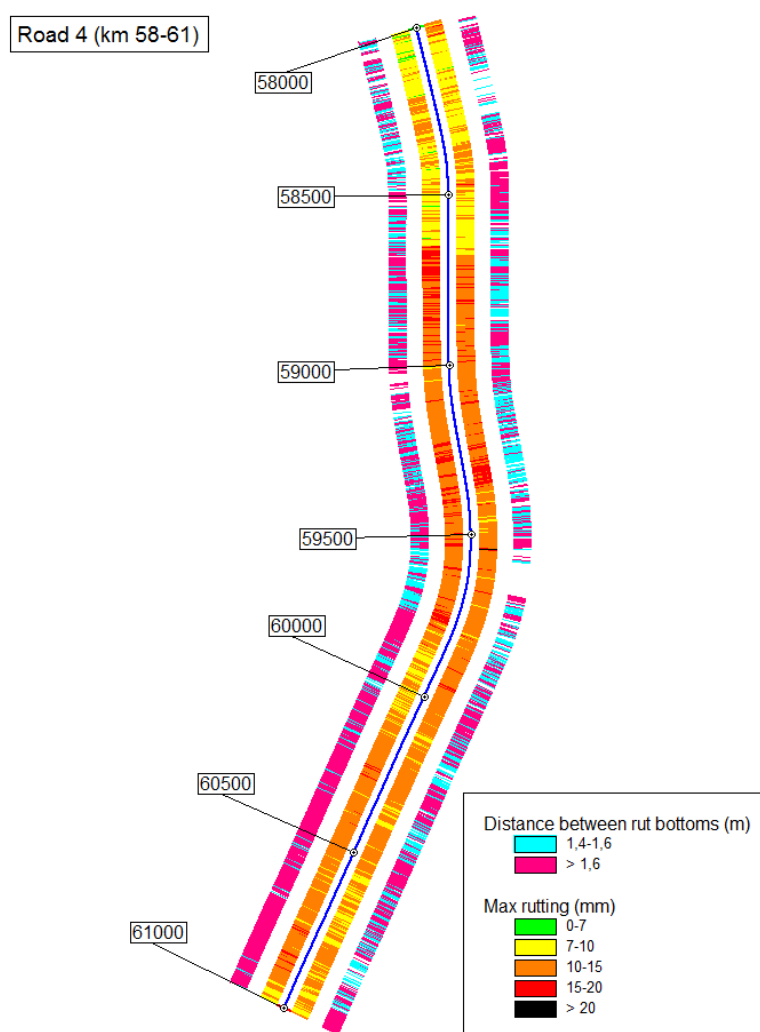


Figure 67_5. Maximum rutting in both lanes (inner lines, colours from green to black) together with distance between rut bottoms (outer lines, colours pink and blue).

6.8 Section 8 – Road 4 km 144-147

The road section 8, road 4 from km 144 to 147, was rehabilitated in the years 2001-2002. Road 4 goes from Tallinn to Pärnu and further to Ikla. In this research the section Uulu - Luuri was examined.

The pavement is in good condition. Interface between new / old stabilisation / bound layers is unclear in drill cores, which might indicate problems with bitumen content? Cracks are in this interface. Drainage condition is adequate / poor. Road section has recently been partly repaved. Reason for damages could be poor quality old bound layers below the new layers. The road section has been rehabilitated only with a new bound base and wearing course overlay. From this section two drill core samples from stabilized course were analysed in laboratory to find out bitumen content. The samples were from chainage 145,65 km and 146,50 km and the bitumen contents were 4,1 and 3,8%, which are normal values.

6.8.1 Designed Structure

Table 68_1 presents the designed structures. The information is based on detailed plans and other information provided by Riigikontroll. The designed structure consists of two pavement layers and a stabilization layer.

Table 68_1. The detailed design information from section 8

Structures location in the survey area	58-61
Pole number	0+00...30+00
Length of structure type	3 km
Materials	Thickness [cm]
Dense Asphalt concrete TAB 12I	4
Porous Asphalt concrete PAB 16 A	6
Bitumen stabilisation mix BS 32	15
Remained old asphalt pavement	20
Gravel or gravelly sand	
sand	
Total thickness [cm]	45

6.8.2 GPR

Pavement thickness fulfills or exceeds the planned thickness through almost the entire section. Interpreted bitumen stabilisation layer is thinner after about 145 500 m and mostly doesn't meet the planned layer thicknesses. Maps and statistics of interpreted layer thicknesses are shown in Appendix 8.

According to GPR data there could be some cracks on the top of the old bound layers or it might also be some kind of geogrid (Figure 68_1). The deviation appears like waves.

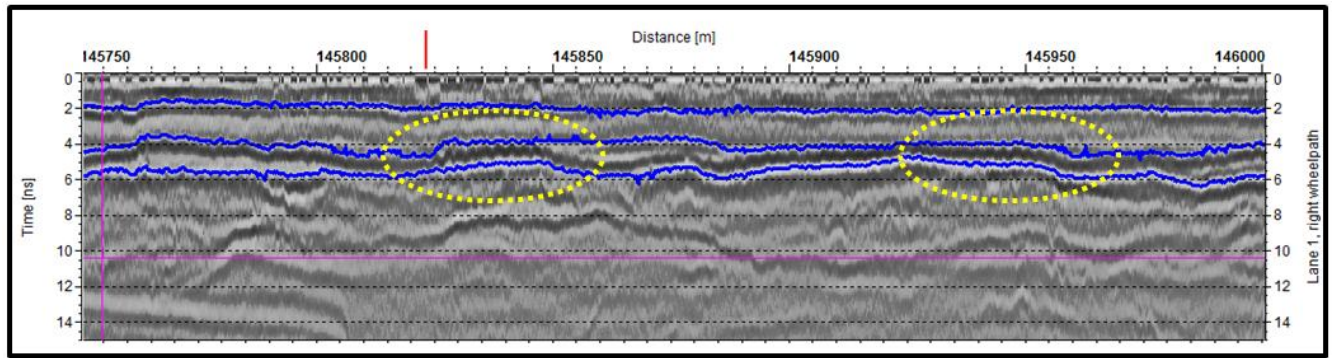


Figure 68_1. Possible crack sections has been circled with yellow dashed lines.

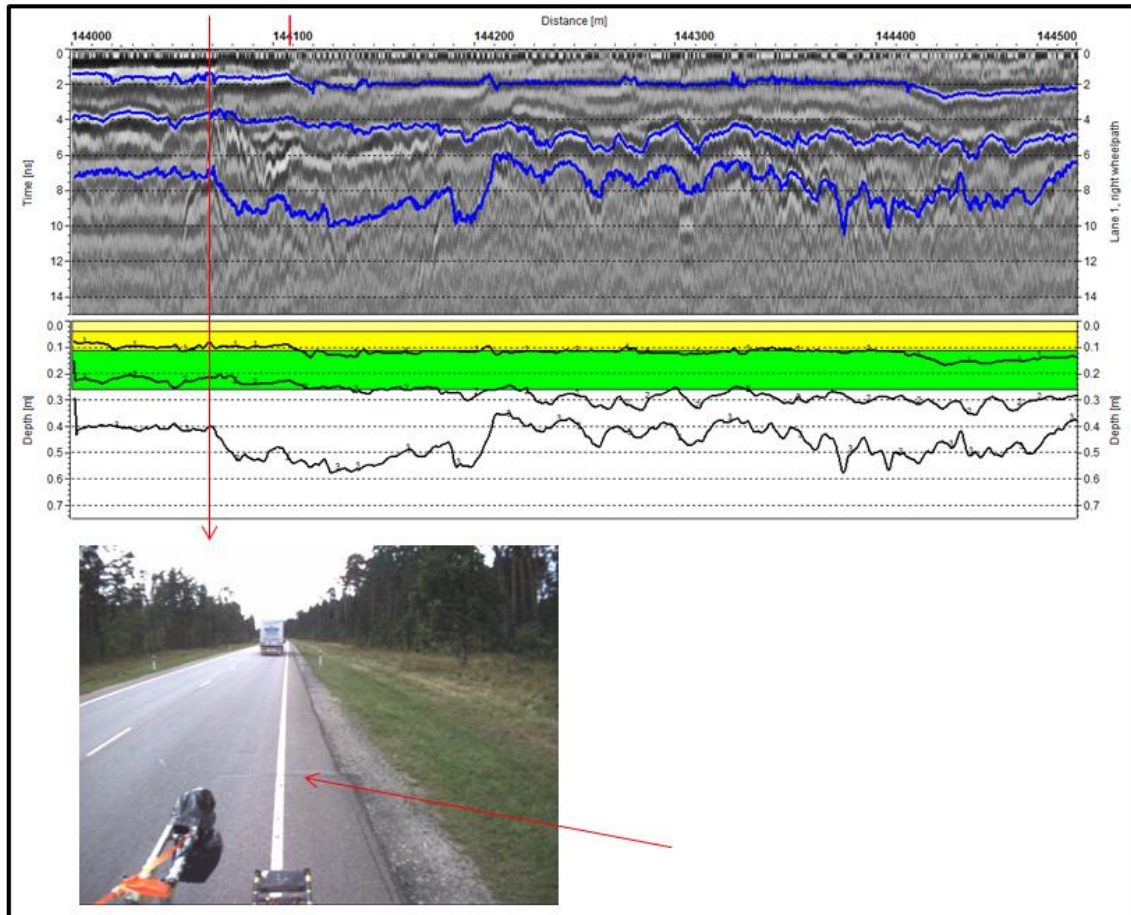


Figure 68_2. Road structure changes at chainage 144060m. The point in the still image and transverse crack on the road surface have been marked with red arrows.

6.8.3 Laser Scanner

Laser scanner data showed slight deformation on road surface and inner slopes (Figure 68_3).

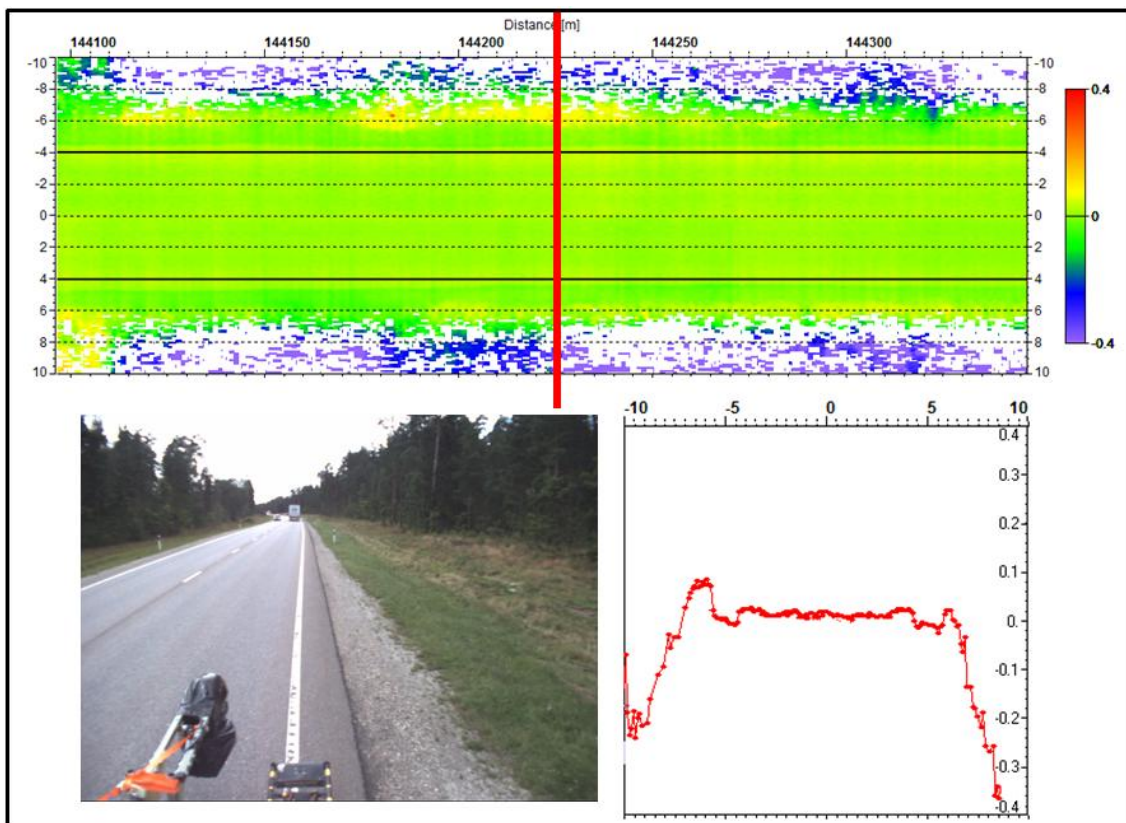


Figure 68_3. Laser scanner surface elevation map from section 8 (road 4). The still image and cross section profile is picked from chainage 144 225m. The black lines on surface map represent the approximated road edges.

6.8.4 Accelerometer

Road is even and the longitudinal roughness on both lanes is quite low (Figure 68_4). There are a couple of acceleration peaks that are caused by transverse cracks, but generally the section doesn't have lot of pavement damage.

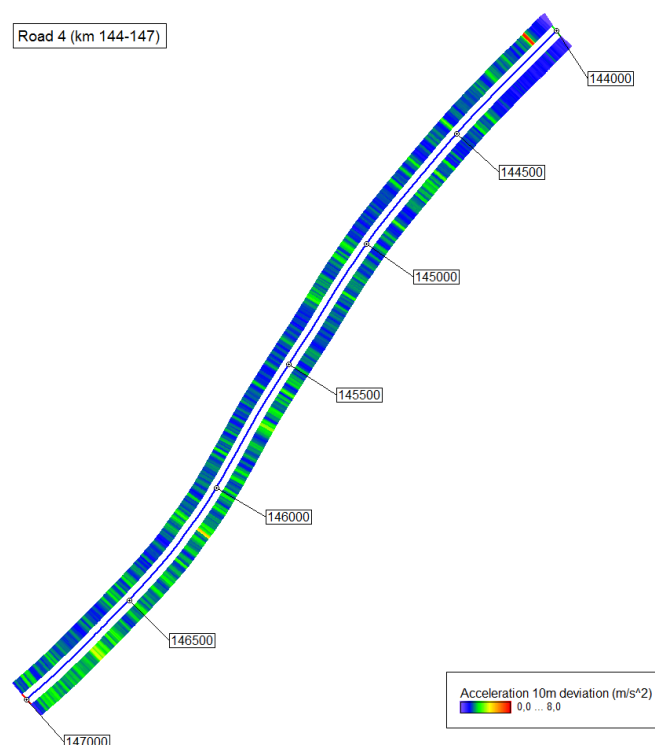


Figure 68_4. Acceleration 10m deviation from section 8 presented as a map.

6.8.5 Rutting

Rutting in the road section is mostly 10-15 mm. Lane 1 has slightly higher rutting than lane 2. In a few places in lane 1 rutting is over 20 mm and maximum rutting is about 26 mm (Table 68_2 and Figure 68_5).

Table 68_2. Statistical results of rutting from section 8.

	Lane 1	Lane 2
Left rutting aver. (mm)	13,2	11,1
Right rutting aver. (mm)	12,2	11,1
Max rutting (mm)	25,7	18,2
Aver. height of the ridge rut (mm)	12,4	12,6

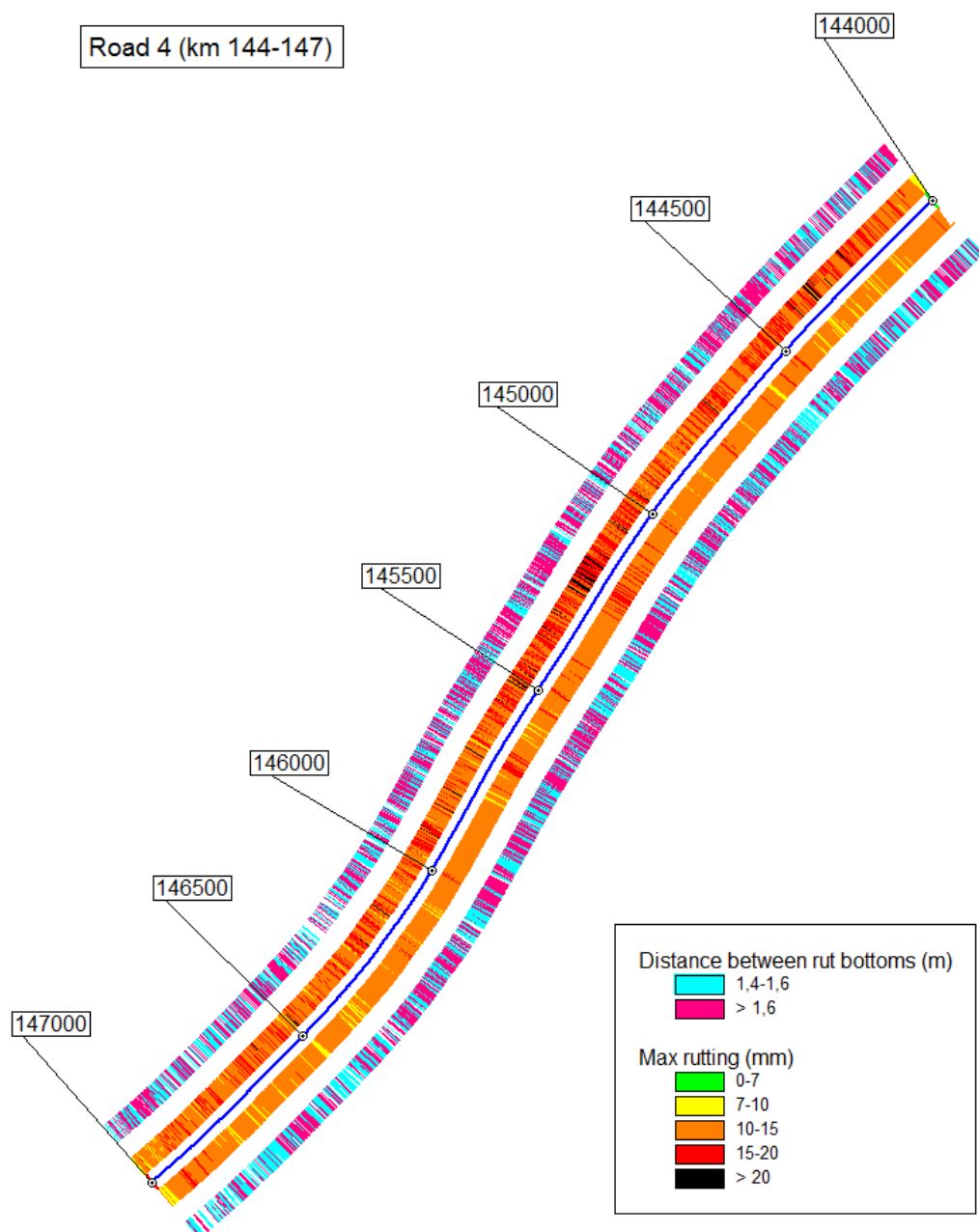


Figure 68_5. Maximum rutting on both lanes (inner lines, colours from green to black) together with distance between rut bottoms (outer lines, colours pink and blue).

6.9 Section 9 – Road 4 km 130,8-133,8

Road section 9, road 4 from km 130,8 to 133,8, was rehabilitated in the years 2010-2011. Road 4 goes from Tallinn to Pärnu and further to Ikla. The rehabilitated section was around Papiniidu pikendus. In this research the section around Papiniidu pikendus was examined.

The pavement is in good condition. However, the structures do not follow the design in every part of the section. There are big variations in both longitudinal and cross sectional layer thicknesses. Road goes partly through a city area. Old road has probably been left in the structure. The road section has been rehabilitated with a “proper” structure. From this section one drill core sample from stabilized course was

analysed in laboratory to find out bitumen content. The bitumen content of the sample from chainage 133,7 km was 1,5%. It is normally too low compared to recommended content (3,0 – 3,5 % in Finland). If the bitumen content is too low, it decreases the water resistance properties of material against permanent deformations. But, on the other hand, according to ROADDEX projects, good results have been gained by adding only 1 % bitumen to the base course.

6.9.1 Design Structure

Table 69_1 presents the designed structures. The information is based on detailed plans and other information provided by Riigikontroll. The plan consists of several new layers, of which the total thickness is 42cm above geotextile and below geotextile 70 cm medium sand, so the total thickness of road structure would be 112cm.

Table 69_1. The detailed design information from section 9.

Structures location in the survey area	130,8-133,8
Pole number	0+00...30+00
Length of structure type	3
Materials	Thickness [cm]
Crushed aggregate mastic asphalt KMA 12	4
Dense asphalt concrete TAB 16 II	5
Porous asphalt concrete PAB 16	5
Precoated crushed limestone MUK 12/32	8
Granite macadam optimum mixture	20
Geotextile	
Medium sand	70
Existing soil	
Total thickness [cm]	112

Comparison to Estonian design guidelines

Comparing the design structure of section 9 to Estonian design guidelines can be said that it fulfills the bearing capacity, rutting and roughness norms. Also designed thicknesses are according to the recommended (Table 69_2), except base & subbase layer is 80 mm too thin. This has no significant effect to the road performance since the drainage layers are 100 mm thicker than recommended.

Table 69_2. Comparison of thicknesses

Layer	Thickness [mm]		Qualify or not
	Designed structure	Guidelines	
Bound	220	190	Yes
Total thickness	1120	1070	Yes
Base+subbase	200	280	No
Drainage layers	700	600	Yes

6.9.2 GPR

Structures do not follow the design in every part of the section. There are variations in layer thicknesses mostly in the longitudinal direction. Granite macadam optimum mixture layer has the most undershoot. It is more than 10 % under the planned thickness in 39-54% of distance. Maps and statistics of interpreted layer thicknesses are shown in Appendix 9.

Geotextile is clearly seen at a depth about 40cm in the structure (Figure 69_1). According to plan, geotextile has been placed as designed. The structure type change occurs at chainage 133640m (Figure 69_2). According to the ground coupled GPR data the total thickness of road structure is quite variable (Figure 69_3). During a close examination some strong reflections were observed in lane 1. These reflections are possibly moisture susceptible materials in the structure (Figure 69_4).

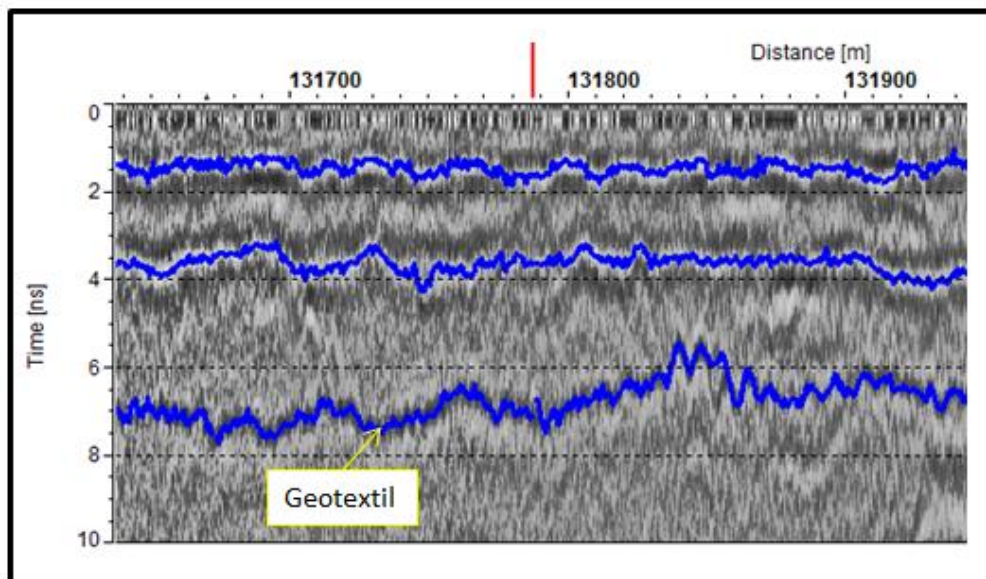


Figure 69_1. Geotextile at the depth of 40cm (about 7ns).

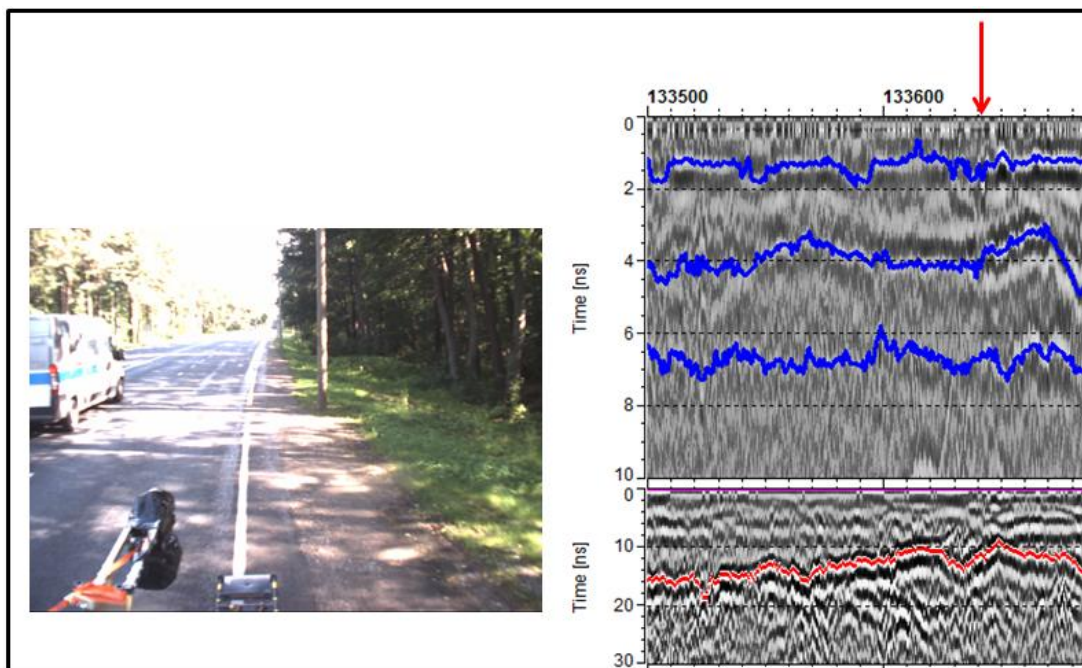


Figure 69_2. A change in the structure type. The point of still image has been marked with red arrow.

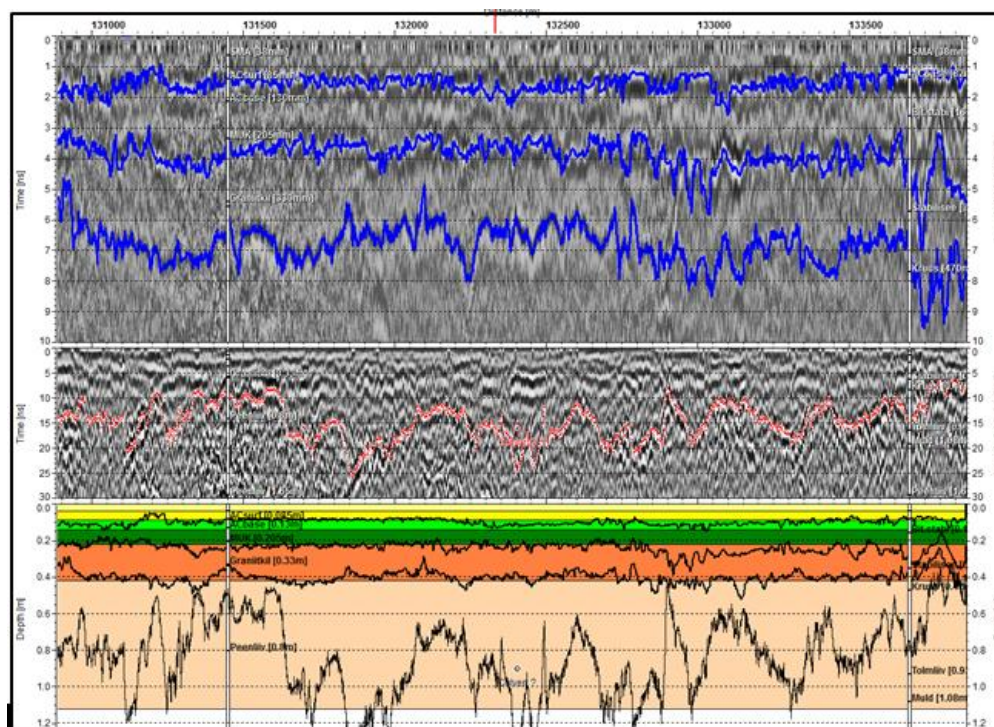


Figure 69_3. Varying total thickness on section 9.

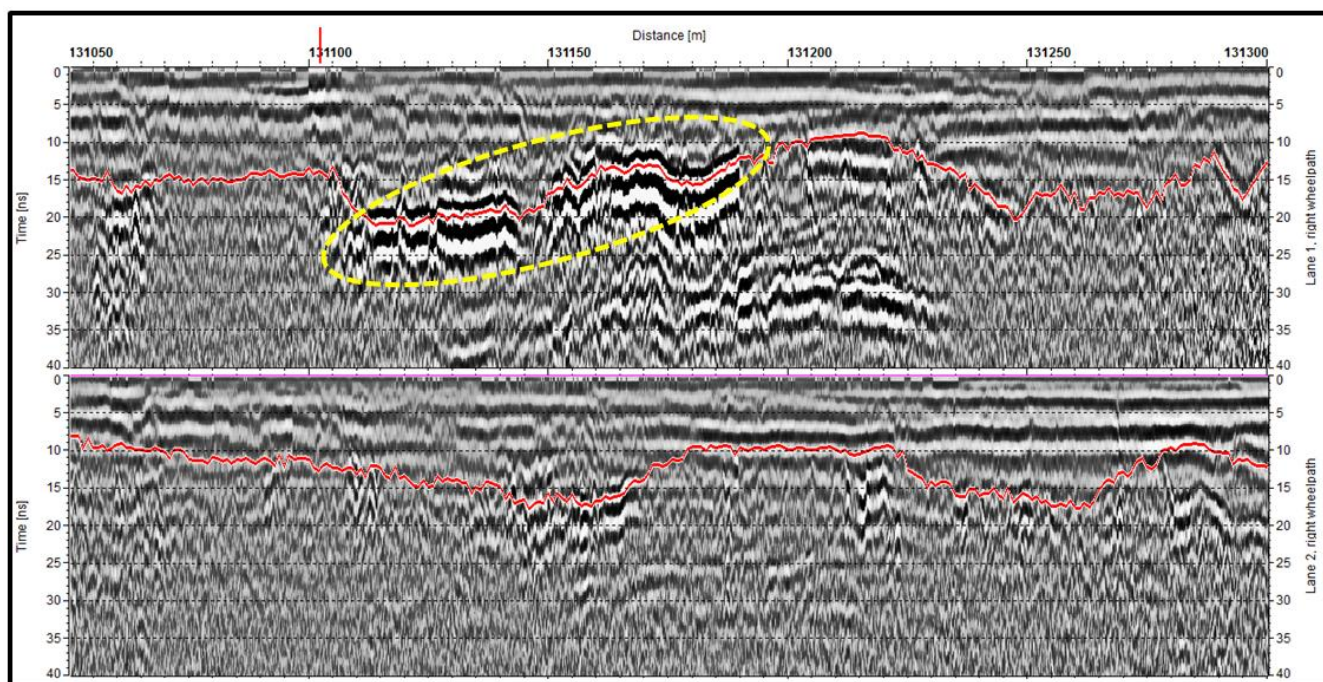


Figure 69_4. Moisture susceptible materials in lane 1, circled with a yellow dashed lines.

6.9.3 Laser Scanner

Examination of laser scanner data showed that road surface is quite even. Road is located in an urban area and the median islands and border stones are clearly seen in the laser scanner data (Appendix 9).

6.9.4 Accelerometer

The pavement in this section is in good condition and the roughness in both lanes is quite low (Figure 69_5). There were 3 traffic lights in the section (131 000 m, 132 870 m and 133 390 m) which affected the acceleration measurements in these places, because the survey car had to be stopped at some of them. In the beginning of the road section the pavement is new until 133 650 m. The largest acceleration spike at 133 650 m is caused by the pavement joint. Other acceleration spikes are caused mostly by road markings.



Figure 69_5. Acceleration 10m deviation from section 9 presented as a map.

6.9.5 Rutting

Rutting in the road section is low, because the pavement is new until 133 650 m. The most rutting is found at places where the cars have to stop for the traffic lights. Maximum rutting at these places is a little below 20 mm (Table 69_2).

Table 69_2. Statistical results of rutting from section 9.

	Lane 1	Lane 2
Left rutting aver. (mm)	8,1	6,7
Right rutting aver. (mm)	7,6	7,5
Max rutting (mm)	18,3	19,8
Aver. height of the ridge rut (mm)	10,2	9,8

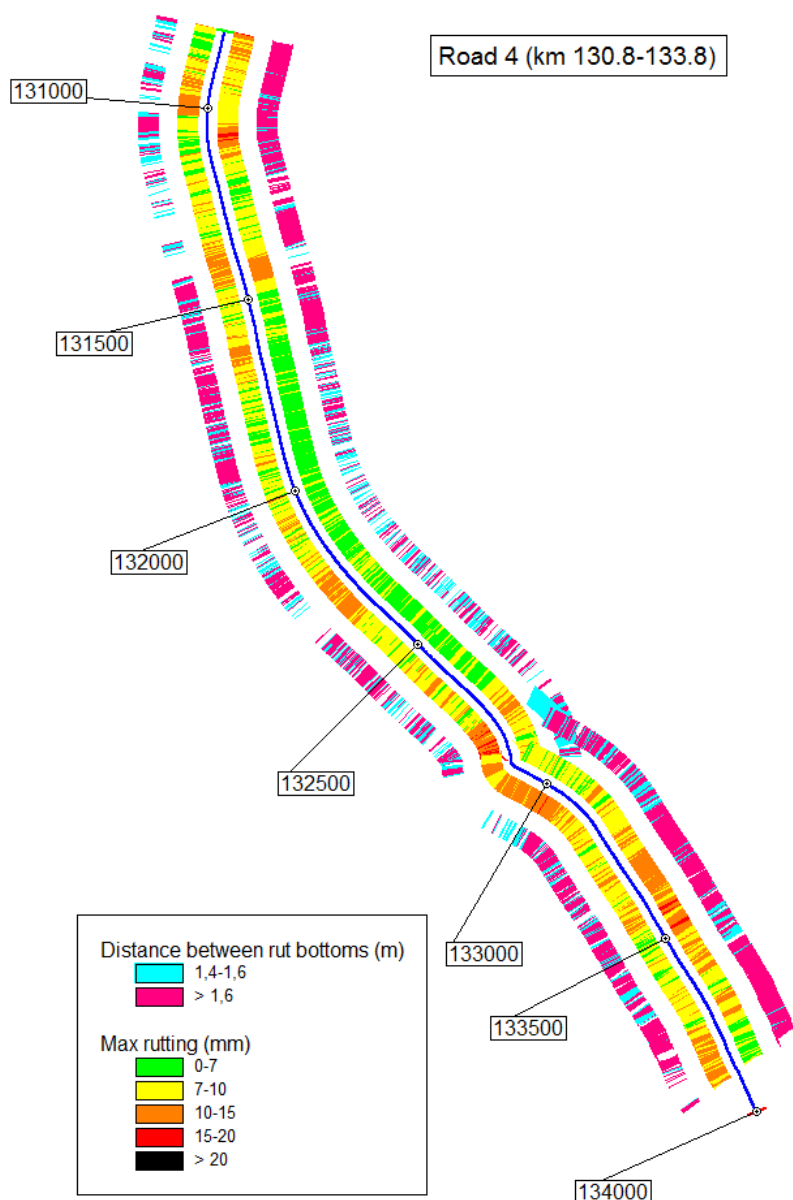


Figure 69_6. Maximum rutting on both lanes (inner lines, colours from green to black) together with the distance between rut bottoms (outer lines, colours pink and blue).

6.10 Section 10 – Road 9 km 58-61

Road section 10, road 9 from km 58 to 61, has been rehabilitated in the year 2008. Road 9 goes from Ääsmäe to Haapsalu and further to Rohuküla. The rehabilitated section was from Palivere to Rannaküla. In this research the section Pälli – Taebla was examined.

Generally the road surface is in good condition. Road goes partly through a city area. The old road has been left under the new structure in places, in some places soil has been replaced. The road has probably been partly widened. The road section has been rehabilitated with a “proper” structure. From this section one drill core sample, taken from chainage 59,98 km, from the stabilized course was analysed in laboratory. The bitumen content was only 0,8% and it is too low compared to normally recommended content. If the bitumen content is too low, the material can

become water susceptible and the risk for permanent deformations will increase. However, according to ROADEX projects, good results have been gained by adding only 1 % bitumen to the base course. In any case if such a low bitumen contents are being used, road designer/contractor should have laboratory results from mixture design to show why this content has been used.

6.10.1 Designed Structure

Table 610_1 presents the designed structures, which should have been implemented in the rehabilitation process. The information is based on detailed plans and other information provided by Riigikontroll. The plan consists of two pavement layers, TAB II 4cm and PAB 16 6cm, stabilisation layer 12cm, crushed, wedged, limestone subbase 12cm and below that a gravelly sand layer >75cm, so that the total thickness of the road structure would be more than 109cm.

Table 610_1. The detailed design information from section 10.

Structures location in the survey area	58-61
Pole number	86+00...116+00
Length of structure type	3
Materials	Thickness [cm]
Dense Asphalt concrete TAB 12I	4
Porous asphalt concrete PAB 16(32)	6
Crushed limestone bitumen impregnated	12
Crushed limestone subbase (wedged) / crushed limestone 4/32	12
Gravelly sand	> 75
Total thickness [cm]	>109

Comparison to Estonian design guidelines

When comparing the design structure of section 10 to the Estonian design guidelines it can be stated that it fulfills the bearing capacity, rutting and roughness norms. Also designed thicknesses are according to the recommended (Table 610_2), except base & subbase layer is too thin. In places the old road has been left into the structure (Figures 610_1 and 610_2).

Table 610_2. Comparison of thicknesses

Layer	Thickness [mm]		Qualify or not
	Designed structure	Guidelines	
Bound	220	190	Yes
Total thickness	1090	1070	Yes
Base+subbase	120	280	No
Drainage layers	750	600	Yes

6.10.2 GPR

Pavement and bitumen stabilisation layers mostly fulfill the planned layer thicknesses, but crushed limestone subbase is too thin through almost the whole section. Undershoot in subbase thickness is on average about 5 cm. Maps and statistics of interpreted layer thicknesses are shown in Appendix 10.

The GPR cross section (measured at chainage 59km) confirms the observation that the old road has been left in the road structure in some sections (Figure 610_1). Longitudinal GPR profiles also show that the bottom of road structures are at different depths in both lines in some places (Figure 610_2). Probably the road has been widened. This might lead to differential frost heave problems later.

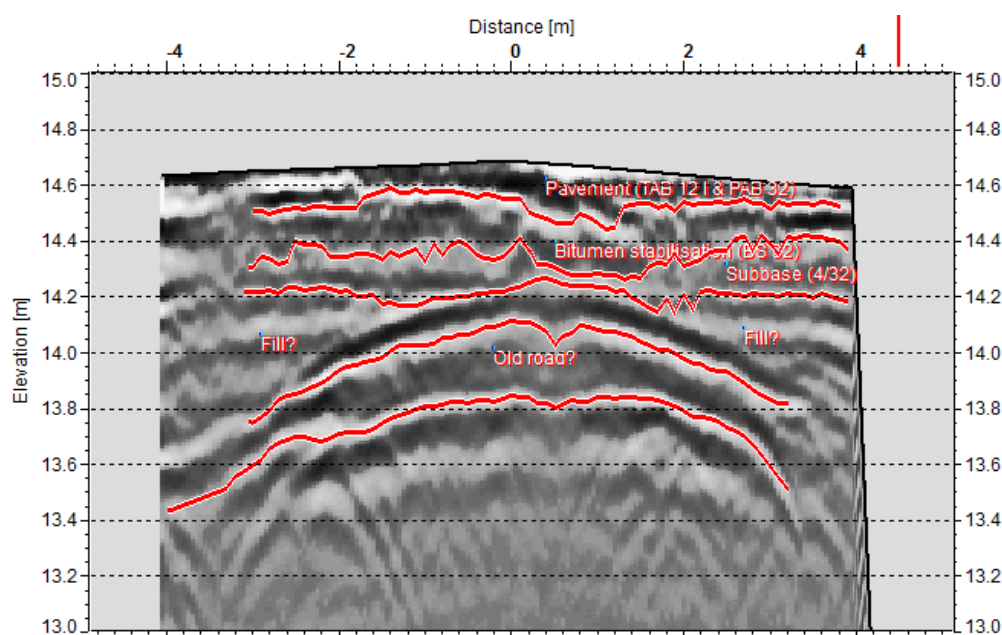


Figure 610_1. GPR cross section from point 59km.

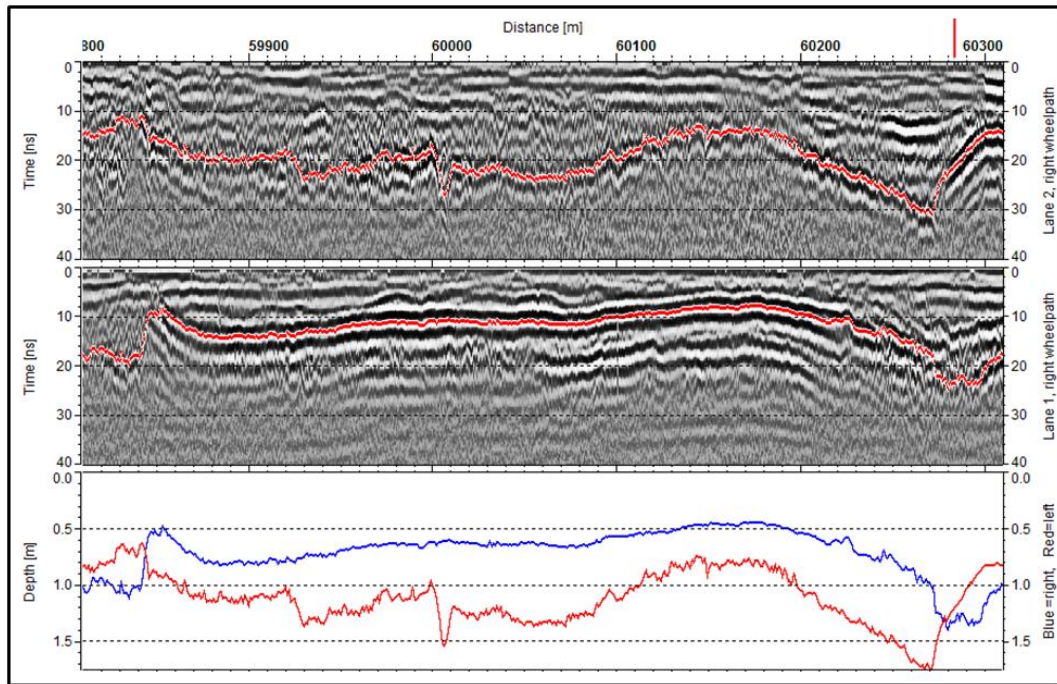


Figure 610_2. GPR longitudinal profiles from Lane 2, right wheelpath (upper) and Lane 1, right wheelpath (lower). Lines in the lowest window represents the depth of road structure (blue = right, red = left).

6.10.3 Laser Scanner

As with the previous section this section 10 is also located in a city area. Examination of the data showed that the road surface is quite even.

6.10.4 Accelerometer

Generally the road surface is in good condition. It has been paved quite recently and there is no significant damage that could be seen in the accelerometer data. The higher acceleration spikes seen between 59 000m and 59 400m in the 10m acceleration deviation data are caused by speed bumps and pavement markings (Figure 610_3 and 610_4).

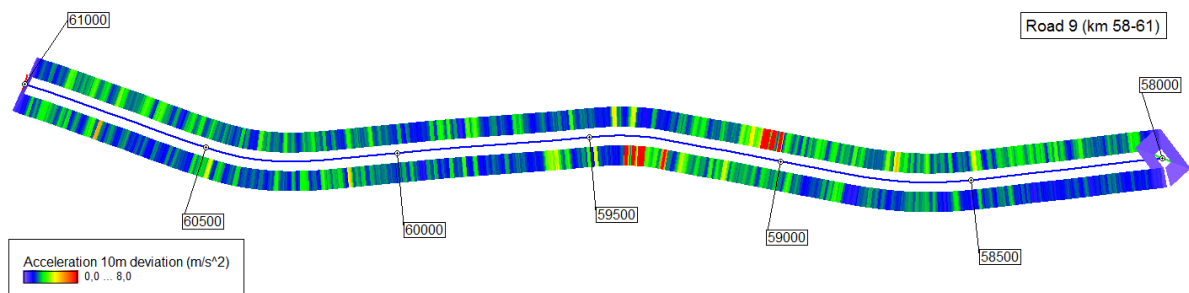


Figure 610_3: Acceleration 10m deviation from section 10 presented as a map.



Figure 610_4. Speed bumps in lane 1 at chainage 59000.

6.10.5 Rutting

Rutting on the road section is low. Average rutting is between 7-9 mm (Table 610_2). The highest rutting values are located near the crossroads (59 100 m and 59 300 m) and can be partly caused by the crossroad paintings (Figure 610_5).

Table 610_2: Statistical results of rutting from section 10.

	Lane 1	Lane 2
Left rutting aver. (mm)	9,0	8,5
Right rutting aver. (mm)	7,0	8,6
Max rutting (mm)	21,7	19,8
Aver. height of the ridge rut (mm)	8,4	8,7

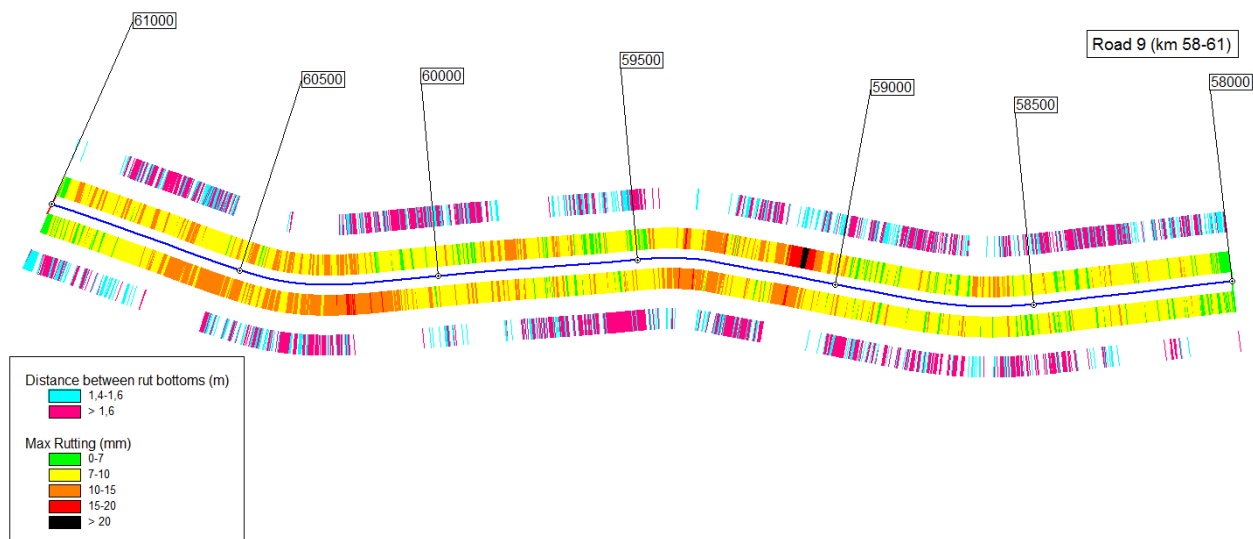


Figure 610_5. Maximum rutting in both lanes (inner lines, colours from green to black) together with distance between rut bottoms (outer lines, colours pink and blue).

7. Summary of the Results

In the following Chapters the results are drawn together. Each of these road sections has its special features. Road quality and drill cores correlate well in general. Section 6 is in the poorest condition of the surveyed roads. It has deep ruts, patches and transverse cracks. According to analysis it can be questioned whether the rehabilitation was performed as it was designed; has the MUK 16/32 layer been laid at all? Sections 5 (a lot of patches) and 7 (ruts, deformations) are also in poor condition. Sections 1 and 2 are in the best condition and sections 9 and 10 are also in good condition. Sections 9 and 10 pass through an urban area.

Damage detected on roads are mainly transverse cracks, ruts, some longitudinal cracks, patches (to repair rutting) and verges on both sides of road. Clogged or totally missing culverts for access roads are also causing damage to the road surface. This is a very common problem in Finland and in Sweden also.

7.1 GPR

Generally there is quite a lot of variation in layer thicknesses in the sections. There are places where thickness is more than 10 % under planned thickness, but also places where thickness is more than 10 % over planned thickness. This variation is seen mostly in longitudinal direction, but also in some places in transverse direction (differences between different lanes). In average the thicknesses mainly fulfill the design demand. It should be noted that in some sections the two top layer pavements could not be separated in the interpretation. This is due to similar electromagnetic nature of these materials (dielectric values are very close each other) and resolution issues with thin top layer (<35mm).

7.2 Rutting

Rutting varies between different sections. There are some sections that have new pavement and only a little rutting, and other sections that have old pavement and a lot of rutting. The most rutting is found in section 6 (Road 2 km 150-153) and in section 3 (Road 1 km 42-45, especially lane 1). These two sections have a lot of places, where rutting is over 20 mm. Sections 2, 7, and 9 also have a moderate amount of rutting, but rutting is usually under 20 mm in these sections. Summary statistics of rutting are presented in Table 72_1.

Table 72_1: Summary of rutting.

	Left wheelpath rutting avg. (mm)	Right wheelpath rutting avg. (mm)	Max rutting (mm)	Avg. height of the ridge rut (mm)
1 / Road 1 (km 64-67)	7,8	7,2	15,9	8,7
2 / Road 1 (km 22-25)	10,8	11,5	20,1	12,0
3 / Road 1 (km 42-45)	14,6	13,4	36,0	17,6
4 / Road 3 (km 82-85)	9,3	8,8	15,8	10,8
5 / Road 3 (km 198-201)	9,0	8,1	17,9	9,5
6 / Road 2 (km 150-157)	17,5	19,2	34,0	19,3
7 / Road 4 (km 58-61)	10,1	11,1	30,3	11,8
8 / Road 4 (km 130-133)	7,4	7,6	19,8	10
9 / Road 4 (km 144-147)	12,1	11,7	25,7	12,5
10 / Road 9 (km 58-61)	8,7	7,8	21,7	8,6

7.3 Roughness

Generally all sections are in pretty good condition and the roughness is quite low. There are some damages in some sections that can be seen in the longitudinal profiles of acceleration 10 m deviation in the Appendices. The lowest roughness is found in section 1 (Road 1 km 64-67) and in section 7 (Road 4 km 58-61). Highest roughness is found in section 5 (Road 3 km 198-201), which has a lot of patches through the whole section. In section 10 (Road 9 km 58-61) the pavement is in good condition, but the speed bumps and road markings raise the roughness values. Summary values of accelerations are shown in Table 73_1.

Table 73_1: Summary of roughness.

	Average of 10m deviation (m/s ²)	Maximum of 10m deviation (m/s ²)
1 / Road 1 (km 64-67)	1,75	3,84
2 / Road 1 (km 22-25)	2,17	11,24
3 / Road 1 (km 42-45)	2,31	16,28
4 / Road 3 (km 82-85)	2,36	10,57
5 / Road 3 (km 198-201)	2,79	13,93
6 / Road 2 (km 150-153)	2,17	13,33
7 / Road 4 (km 58-61)	1,71	5,27
8 / Road 4 (km 130-133)	2,12	8,02
9 / Road 4 (km 144-147)	2,15	7,81
10 / Road 9 (km 58-61)	2,38	14,62

7.4 Bearing Capacity Analysis

Bearing capacity of the test sections was analysed from the Estonian road data base and provided by the client. Most of the data was quite old so it does not reflect well current condition but the statistical analysis shows that E2 values meet the specification 240 MPa (table 74_1). In test section 4 there one single point and in section 5 there were two single points where the dynamic moduli E2 was less than 240 MPa. And also in these cases the static moduli values, which are slightly higher, met the Estonian standards. To be noticed: the authors are not aware if temperature correction was used and what Poisson's ratio has been used in the calculations.

Table 74_1: Statistical analysis results of the bearing capacity values from the Estonian road data base.

Section	Road	(km)	FWD year	Constr yr	E2 mean	E2 min	E2 max
1	T1	64-67	2011,00	2009-2010	324	286	378
2	T1	25-25	2006	2005-2006	455	282	620
3	T1	42-45	2006,00	2005-2006	348	280	506
4	T3	82-85	2007,00	2005-2007	363	230	467
5	T3	198-201	2007,00	2005-2007	295	229	395
6	T2	150-153	2003,00	2005-2007	488	317	1058
7	T4	58-61	2002, 2009	2001-2002	481	265	740
8	T4	144-147	2003,00	2001-2002	355	276	461
9	T4	130,8-133,8		2010-2011	no data		
10	T9	58-61	2010,00	2008	344	267	476

7.5 Transverse cracks

Transverse cracks were classified in to 3 classes by the acceleration value. Class 1 is a transverse crack that doesn't cause a vibration sensed inside a vehicle at 60 km/h speed. Class 2 is a transverse crack that causes a vibration that can be sensed inside a vehicle at 60 km/h speed. Class 3 is a transverse crack that causes a strong vibration inside a vehicle at 60 km/h speed.

Section 1: New pavement, no transverse cracks.

Section 2: Some transverse cracking. About half are class 1 and half class 2, one class 3 (~23 800 m)

Section 3: Only a few class 1 transverse cracks.

Section 4: Only a few transverse cracks, but all are class 2 and one class 3 (~83 320 m).

Section 5: Low amount of class 1 transverse cracks.

Section 6: A lot of transverse cracks. All are class 2 or class 3. Transverse cracks have been patched and the patches are uneven.

Section 7: Only a couple of class 1 transverse cracks.

Section 8: One class 1 transverse crack.

Section 9: No transverse cracks.

Section 10: No transverse cracks.

7.6 Road widths

Road widths were measured from laser scanner data. A summary of the results is presented in table 76_1 and it shows that they are in general quite close to design widths.

Table 76_1. Measured and designed road widths.

Section	Measured width		Pavement		Designed width	
	Lane 1	Lane 2			lane	paved road
1 (road 1, km 64-67)	3,77	3,67	11,43		3,75	11,5
2 (road 1, km 22-25)	3,87	3,83	8,89 (excl. right servicelane)		3,75	11,5
3 (road 1, km 42-45)	3,79	3,77	11,52		3,75	11,0 - 11,5
4 (road 3, km 82-85)	3,55	3,56	7,95		3,5	8
5 (road 3, km 198-201)	3,58	3,56	7,89		3,5	8
6 (road 2, km 150-153)	3,70	3,81	9,11		3,75	9
7 (road 4, km 58-61)	3,79	3,84	8,94		3,75	9
8 (road 4, km 144-147)	3,72	3,80	8,89		3,75	9
9 (road 4, km 130-133)	3,66	3,66			3,5/ 3,75	11
10 (road 9, km 58-61)	3,72	3,77	8,92		3,75	9

7.7 Statistics of Rutting and Roughness

The roughness and rutting values (provided by Riigikontroll) were examined statistically. It can be said that roughness values were at quite low level. In average they were at the level of 1 mm/m and no linear increasing was detected. This means that values are below the critical limit (chapter 5.5.2 Roughness performance). Figure 77_1 presents an example of IRI values from road section 6 and Figure 77_3 from road section 8.

Statistical analysis was also made from rutting values. Some sections like section 3 and section 5 had had rut repairs and patching made after construction, which affect the measured rutting values. Figure 77_2 presents rutting values and their growth rate from road section 6, which had one of the highest rut increase rates of the surveyed sections. Rutting growth rate is on this section about 1 mm/year. Figure 77_4 presents rutting values from road section 8, which was built at the same time as

road section 6, but has lower rut increase rate (about 0,6 mm/year). Measured rutting from 2011 was on the road sections mostly below the critical limit 20 mm, only a few measured 100 m average values were 20 mm or over.

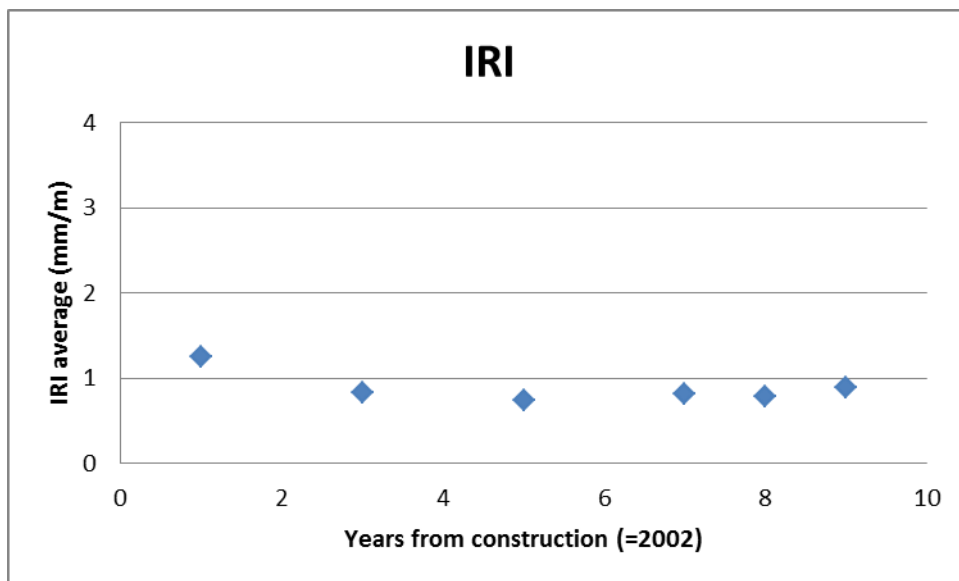


Figure 77_1. IRI values from road section 6 (road 2, km 150-153).

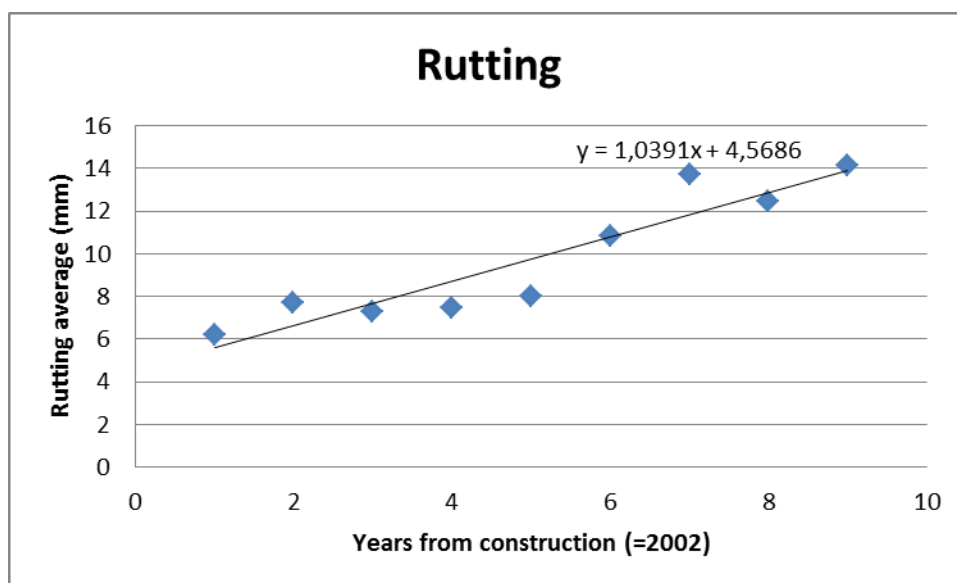


Figure 77_2. Rutting values from road section 6 (road 2, km 150-153).

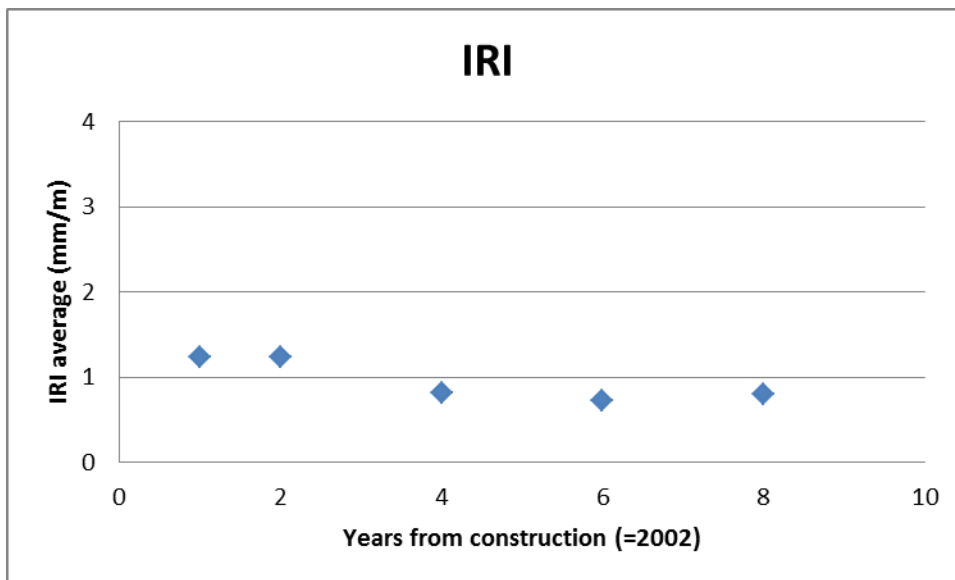


Figure 77_3. IRI values from road section 8 (road 4, km 144-147).



Figure 77_4. Rutting values from road section 8 (road 4, km 144-147).

8. Summary and conclusions

The results of the tested 10 road sections show that almost all the sections have been slightly oversized using thick and safe structures – a new bound base and wearing course on the top of old structures. Thanks to that, the roads are currently performing quite well with no major problems except in sections 5 and 6. In section 5 thicker unbound structures should have been used instead of “new layer on the top” solution. Section 6 is more complex and no clear reason could be found. Most likely the problems are related to building stiff bound layers on top of the relatively soft tarmac layer.

Based on the Estonian road data base bearing capacity results all the measured road sections met the Estonian bearing capacity requirements.

Compared to Roadscanners experiences from similar projects in Finland and Sweden these roads, on average, are in good condition. Positive finding was that rut depth development was quite even, which is a sign of a well designed, well built and mainly well maintained road. The only exceptions were sections 5 and 6 where road problems could be partly explained by poor drainage.

Some general comments about the design and construction are given in the following.

Design

In most cases thick bound layers have been used and old bound layers have been left below new ones without any consideration as to whether this is the optimal solution. Only in section 1, 9 and 10 other design structures have been used, in the rest of the sections only new pavement or pavement & stabilisation layers have been added to the top of the old structure.

The comparison calculations (table 54_3) showed that the theoretical life time of the bound layers is in certain roads quite big, while the life time in foundation level is much shorter. Especially in road section 5, which had some problems, the difference is big (bound >30 years, foundation 5 years) and this can be explained by relatively thin total structure thickness (240 mm bound + 250 unbound). This structure will be easily exposed to Mode 2 rutting (deformation in foundation level) especially during spring when the frost susceptible subgrade is thawing.

Other sections, with life time predicted shorter than 15 years, were section 2 with silty subgrade (14 years) and section 8 with clay subgrade (9 years). These sections however were in relatively good condition. Slight subgrade related deformation could be located in direction 1 in section and in section 8 localized rutting also in direction 1.

If the bound layers are thick, it is very tempting to solve the bearing capacity problems by increasing only bound layer thickness, even though increasing unbound road structure thickness would be a better solution. This is because a new bound layer on the top is much cheaper solution than milling away old asphalt, adding new unbound layers and bound layers. Increasing unbound layer thickness often increases grade line also and requires more land area for the road.

Only adding new layers on the top is a known risk that might lead to failures within a few years after construction. However, a rule of thumb used in USA is that after 5 years from the construction, if less than 5 % of the road section has failed and needs repair, this risk is acceptable.

On the other hand, the Mode 2 rutting in foundation level is extremely sensitive for poor drainage maintenance. If ditches are not kept open and their bottom is not deeper than road structure level, water infiltrates in to the road structures and leads to deformations in road structure - subgrade interface. In that case the reason for the failure is not the design but poor drainage maintenance. In both test sections, 2 and 8, problems were observed with drainage condition, which will increase the risk for the failures in the future.

In Estonia one clear problem to be fixed in the future is that there are no separate norms and guidelines for road rehabilitation. Building a new road from new and well known materials is totally a different task compared to rehabilitating an old road with long construction history and when old, worn and partly disintegrated materials are present. In rehabilitation, good information from old road structure and its material properties are critical in order to be able to make reliable and sustainable design solution. Also the dimensioning procedure has to be slightly different when strengthening or rehabilitating an old road.

EU funded ROADDEX project has done research how road condition management process can be made economically more efficient and sustainable. The key word in this process is focus. Focus on the problem diagnostics, focus on the weakest sections, focus on correct timing and focus on the preventative maintenance. The results of the project point the economic benefits of making a detailed diagnostics of the road and the making a rehabilitation design to repair the source of the problems instead of fixing the symptoms. When this is correctly done using modern survey and analysis techniques, the rehabilitation budget will go down 10 – 60 % without compromising with the quality. And because this solution increases the pavement life time, the annual paving costs can be reduced up to 50 %.

Construction

Structural thickness deviation was quite high and a surprisingly small amount of structures were within 10% target limits. This shows that there is still need for improving construction techniques and practices. However total thickness of bound and unbound layers mainly met the standards.

In general, based on the Roadscanners experience from numerous projects in different countries, the road structures surveyed in this project have been built relatively well and no major cheating with thicknesses of different structures could be found. The thicknesses are slightly thinner in one place but they are thicker in next place which is typical when asphalt plant weigh is controlling the process.

In ROADEX report “ROADEX Benefits and saving – achieving more with less” there is a classification of different risk scenarios for cheating with structures. No risk scenario with less than 10 % thinner structures is acceptable and is within the survey accuracy limits. The “low risk scenario” means 10 - 20 % average thinner structures and in Estonia test tests certain sections these structures could be found but they were mainly compensated with thicker bound layer on the top or below, so total structure thickness was adequate. For example some separate unbound layer thicknesses were detected to belong “low risk scenario” category like section 1 fine crushed granite mix and sand embankment, section 9 granite macadam mix and section 10 crushed limestone subbase, but as mentioned they were separate layers, not whole road structure. The “high risk scenario” structures (structure are thinner up to 40 %), which are very profitable to contractors, could not be found.

Maintenance

One critical issue noted in this project was that drainage condition was not always acceptable, even though the roads were relatively new. This may lead to rapid deterioration of the road, no matter if the road structures were built well. The good thing in Estonia is that the thicker the bound layers are, the smaller the economic effect of poor drainage performance is – and all the tested sections had thick bound layers. Still in this project many sections could be found where poor drainage has already a major effect to pavement performance. This means that in the future, more focus should be paid to control good drainage performance.

The economic effect of poor drainage can be really dramatic to pavement life time. ROADEX report “ROADEX Benefits and saving – achieving more with less” shows calculation, where up to 40-60 million euro from annual 160 million euro annual paving costs in Finland could be saved if, and when road drainage is improved and kept in good condition after that. That is why it is recommended that better drainage maintenance standards should be used in Estonia to protect current pavement structures and to ensure their long life time and minimize annual paving costs in long term.

Appendices

- Appendix 1:** Detailed results of section 1
- Appendix 2:** Detailed results of section 2
- Appendix 3:** Detailed results of section 3
- Appendix 4:** Detailed results of section 4
- Appendix 5:** Detailed results of section 5
- Appendix 6:** Detailed results of section 6
- Appendix 7:** Detailed results of section 7
- Appendix 8:** Detailed results of section 8
- Appendix 9:** Detailed results of section 9
- Appendix 10:** Detailed results of section 10
- Appendix 11:** The results of drill cores and sieving
- Appendix 12:** Principles of drainage evaluation
- Appendix 13:** Modules



Rovaniemi
Varastotie 2
FI-96100 Rovaniemi
Tel. int. +358 (0)207 815 660
Fax int. +358 (0)207 815 662

Tampere
Yliopistonkatu 58 D
FI-33100 Tampere
Tel. int. +358 (0)207 815 661

Helsinki
Pasilanraito 5
FI-00240 Helsinki
GSM int. +358 (0)40 594 9972

Roadscanners Sweden AB
Ålkottsgatan 10
S-78452 Borlänge
Tel. int. +46 243 217 960
Fax int. +46 243 217 961