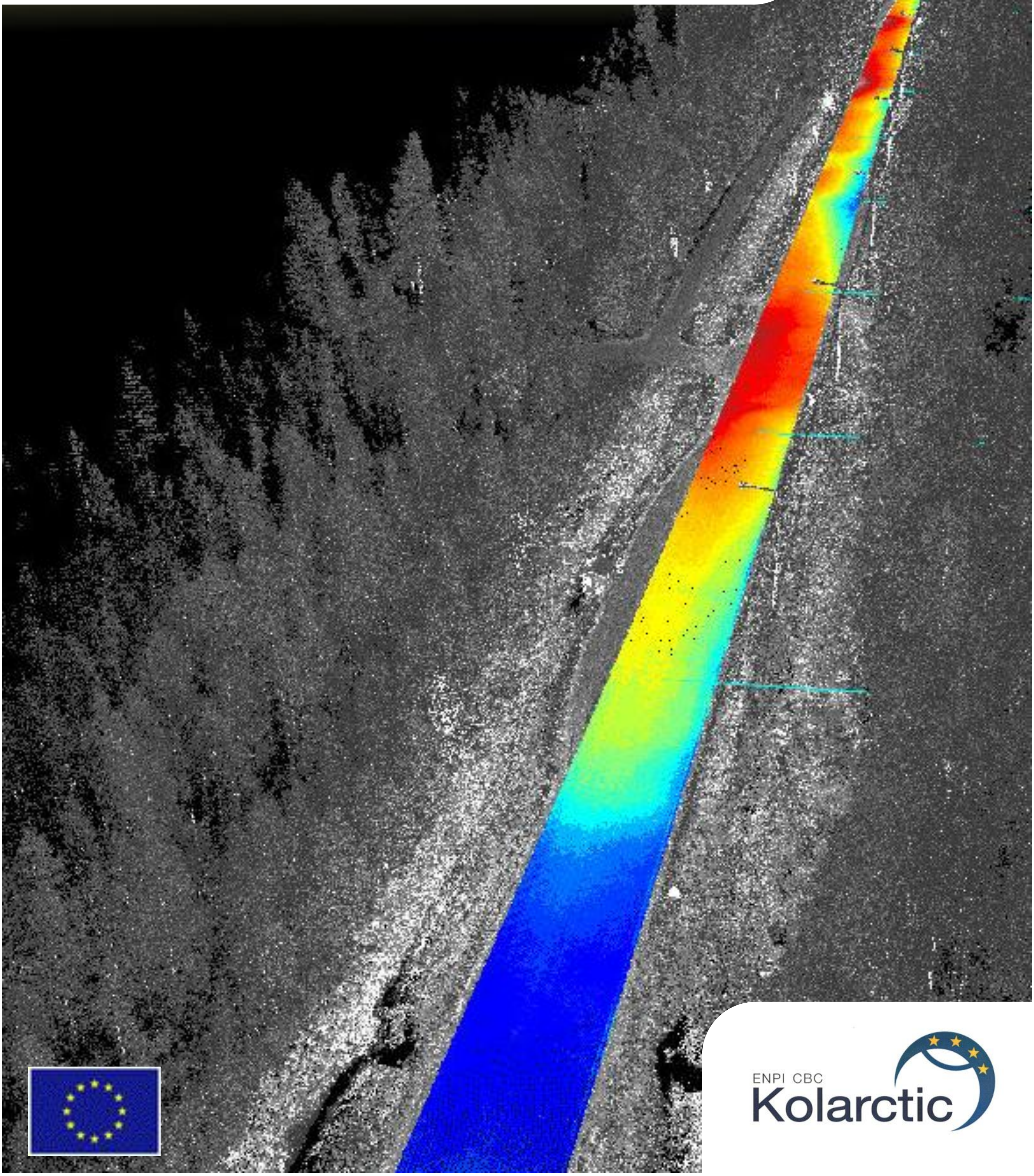
Evaluation of Heavy Haulage Impact on Road Structures

Barents Finland Case Study on HW 4



ENPI CBC Kolarctic

Evaluation of Heavy Haulage Impact on Road Structures

Barents Finland Case Study on HW 4

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Abstract

This report is a part of Activity 3 of the Kolarctic ENPI Programme's project "Barents Low Volume Road Management". This "Case Study Lapland" has focused on describing and testing the technologies that can be used when evaluating the risks that heavy vehicles pose to a road´s structural and functional performance if total weights are increased. These technologies were tested on two road sections from Hw 4, north of Rovaniemi in Finnish Lapland. The key testing techniques were laser scanner technique, ground penetrating radar technique, falling weight deflectometer technique and digital video data.

The collected data was analyzed using different software packages and road problem diagnostics was used to classify the road into different risk classes. The remaining lifetime calculations were performed in each risk class with current heavy traffic and higher traffic amount options. Finally calculations were made regarding the impacts of heavier truck configurations on the road structure.

The results of the structural analysis showed that road structures in both test sections of highway 4 are in relatively good shape and because of thick pavement structure the displacements in the road structure / subgrade interface were relatively low. Lifetime of the bound layers was shorter but it can be extended with a thicker overlay. However, a poorly performing road drainage system is causing differential frost heave problems leading to permanent deformation problems during the spring thaw weakening period.

Impact analysis calculations concerning heavier vehicle options than the standard 60 ton truck showed that longer and heavier vehicles cause higher displacement in the road structure/subgrade interface but the strains in the upper part of the pavement structure are even lower with 72 ton and 90 ton truck options compared to the 60 tn truck.

Preface

The Barents Low Volume Road Management (BLVRM) project is a technical international project between Lapland Centre for Economic Development Transport and the Environment (Finland), Arkhangelsk Regional Road Administration “Arkhangelskavtodor” (Russia), Murmansk Regional Road Administration “Murmanskavtodor” (Russia) as partners. The Federal State Institution "Directorate of the Federal Road St. Petersburg - Murmansk FGU UprDor Kola, Karelia (Russia) and the Ministry of Construction of Karelian Republic (Russia) are associated partners of the project. The Lead Partner is OOO Avtodoroshnii Consulting (Russia). Lapland Centre for Economic Development Transport and the Environment has managed this Case Study in Lapland. Project consultant is a consortium formed by Roadscanners Oy and Pöyry Finland Oy (Finland).

General objectives of BLVRM project are:

- Harmonization of regional practices on the voluntary basis in Barents low volume road network management rather than by directives and
- Developing the economy of Kolarctic core regions through improving of their currently non-adequately managed low volume road networks resulting in better economic activity and improved access to their regional, national and international markets.

Specific objectives of BLVRM project are:

- Harmonization of principles and technologies of low volume road maintenance on the territory of Barents Region;
- Increasing road networks sustainability and decreasing negative impacts of nature, climatic and seasonal character on road performances;
- Optimizing costs on low volume roads with more appropriate technologies, techniques and materials taking account of local specifics;
- For the Russian road sector: Entering an innovational space formed by the road transport cluster of the Barents Region countries to speed up solving of specific problems of remote peripheral districts that need better transport accessibility as the main prerequisite for business activity, higher employment rate and quality of life of local population.

The authors would like to thank Lapland Centre for Economic Development Transport and the Environment for well-functioned client-relation, the BLVRM Steering Committee for its encouragement and guidance in this work. One aim of the BLVRM project is to disseminate the Northern Periphery “ROADEX I…IV projects’ know-how to Russia. The authors would like to thank about full co-operation with ROADEX IV - project Lead Partner, the Swedish Road Administration, Northern Region.

This report is the first of the technical reports series in BLVRM project, the others being:

- Report 2: Heavy Haulage Impact Evaluation, Method Description
- Report 3: Case Arkhangelsk, Heavy Haulage Impact Evaluation, Virtual Simulation
- (Report 4: Case Murmansk: GPR Based Road Condition Monitoring Based on Field Results from 2008)

Contents

1. Introduction

A common feature shared by all road networks in the Barents area is long hauling distances that generate extra transportation costs. The competiveness of the forest and mining industries is especially dependent on the transportation costs. One alternative to reduce these transportation costs, and also carbon emissions, is to use heavier and/or longer truck configurations when transporting raw materials to processing plants and further to the world markets. Results of different heavy haulage pilot surveys have shown that duplication of net weight in trucks will reduce transportation costs by 25 – 30 %. One example of such a project, currently ongoing, is the ETT project (En Trave Till) in Sweden where timber is transported on specified main road transportation routes using 30,5 m long and 90 ton “road train” with truck and two trailers (figure 1).

Before heavier haulage systems can be used the organizations in charge of managing the road networks need to be aware of the impact these trucks will have on the condition and operational procedures of roads, bridges as well as to the environment and traffic safety etc. Different aspects of this type of impact analysis are described in figure 2.

Figure 1. A 30,5 m long and 90 ton heavy truck tested in “En Trave Till” project in Northern Sweden.

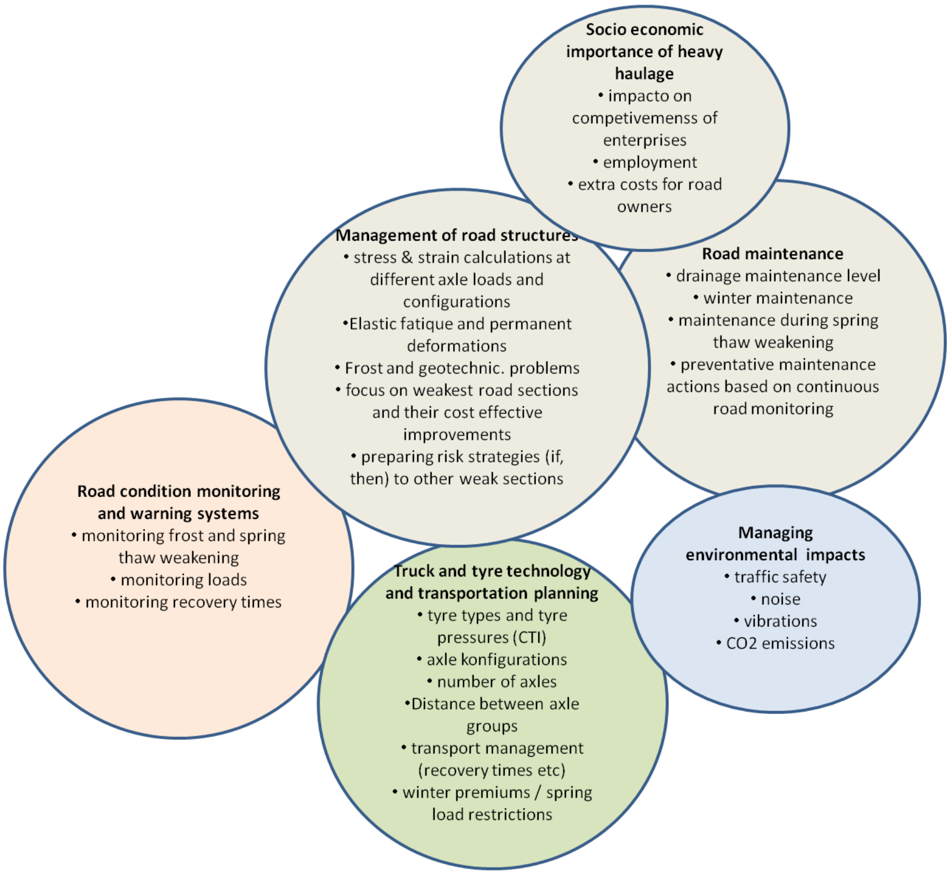


Figure 2. Areas and specific issues that should be evaluated in a heavy haulage impact analysis.

This area case study of Lapland will focus on testing and describing the technologies that can be used when evaluating the risks from increasing the total weights of heavy vehicles (40 tn, 60 tn, 80 tn, 100 tn). This project was divided into the following parts. First, diagnostic measurements were conducted on the selected test roads in order to assess the general condition of the road and the “weakest links” in the road structure and where they were geographically located. Once the diagnostics were completed, calculations were made concerning the remaining lifetime of these roads and about the general stresses and strains in the test sections. Based on the results of these calculations an evaluation of the maximum loads, axle and the tire configurations and tire pressures that could be used on the road networks during different seasons was made. Finally a rough evaluation was made and the additional recommended measures that would decrease the risk of severe road failures caused by heavy vehicles were reported.

This report publishes the key results of the case study Lapland, which was based on two road sections, 505 and 515 from highway 4 between Rovaniemi and Sodankylä. It demonstrates how this heavy haulage impact evaluation can be done in practice.

2. Survey Techniques Used

The survey techniques used in this project are described in the following pages.

2.1 Laser scanning

A mobile laser scanning survey was conducted on road section 505 by GEOVAP Ltd from Czech Republic using a Quantum 3D technique. This technique provides exact point cloud data of the road surface and its surroundings and this data can be used in road geometry analysis, road cross section analysis, drainage analysis and frost heave analysis. Because one of the main goals was to measure frost heave in the whole pavement area, section 505 was surveyed twice: first in April when there was maximum frost but the pavement surface was free of ice (figure 3). The measurements were repeated in early June after the greatest part of the frost causing frost heave had melted, but the vegetation did not disturb the measurements. The difference between the z-coordinates (height) from the two point cloud datasets produced during the two measurements was then calculated. That difference is equal to the amount of frost heave. Quantum 3D laser scanner data was also used to make an accurate map of the shape of the road surface.

Figure 3. GEOVAP Quantum 3D mobile laser scanner vehicle in April 2011.

In addition to high precision Quantum 3D mobile laser scanner surveys the road was also mapped using the RDLS laser scanner system developed by Roadscanners Oy. This data was used mainly in drainage analysis.

2.2 GPR surveys

Both road sections were surveyed with ground penetrating radar instruments in order to produce a 3D image of subsurface structures. In these surveys a new GSSI SIR-30 high speed and high resolution GPR unit was used in order to obtain the best possible data over the road width from seven survey lines (road center, inner wheelpaths, lane centers and road edges). The antennas were also the latest technology from GSSI: an improved 2.0 GHz horn antenna for pavement and base course measurements and a new 400 MHz high speed data collection antenna for deeper road structure were used.

After a preliminary GPR data analysis, cross section data collection with GPR was done in early July on both road sections. In this survey GPR data was collected from altogether 40 cross-sections representing typical road structures. A GSSI SIR-3000 and two different antennas: a 1.5 GHz high frequency and high resolution antenna for top layers (down to 80 cm) and a 400 MHz antenna for overall structure thickness, embankment and subgrade soil were used.

All of the GPR data was processed and interpreted with Road Doctor™ Pro software. The structural layers interpreted from the GPR data were the pavement (the bound layers), the base / sub-base course layers and the total thickness of the pavement structure and embankment. The GPR data quality was good and the interpretation process showed quite clear structures and especially interpretation of the top layers of section 515 was easy. However there were no drill cores available for this project to support the GPR interpretation.

2.3 FWD surveys

The falling weight deflectometer surveys using KUAB deflectometer were conducted by Oulun Geolab Oy. Since it was obvious that the weaker road lane was the southbound lane towards Rovaniemi, the FWD survey was made in direction 2, from north to south. The point interval was 50 m. The surveys were done in August.

In addition to the usual deflection information, the time history data was also recorded in order to get information of possible recovery times. All the collected data was processed and analyzed using Road Doctor™ Pro software.

2.4 Digital videos; drainage and pavement distress analysis

For video data collection, a Road Doctor™ CamLink system was used with a two camera setup. The system is designed to collect videos, audio commentary and drainage or pavement distress inventory on the road, together with GPS coordinates. Digital videos were collected in May to evaluate the drainage of the road as well as collecting the video for pavement distress analysis. All the videos were taken in both directions including a road and a ditch camera.

The drainage analysis was made in mid-May, when the snow had melted and the vegetation was not yet interfering with the evaluation. The initial evaluation was made from the vehicle during the video shoot and the evaluation was reviewed in the office to correct any mistakes. The analysis included right and left side ditch condition evaluation, outlet ditch evaluation and road elevation analysis (embankment, 0-level, road cut, side sloping ground).

2.5 Profilometer data analysis

The profilometer history data was provided by ELY-center of Lapland and the biannual roughness and rutting data, starting from 2001, provided good historical data for diagnostic calculations. The older data was, in most of the cases, measured only in direction 1 but in 2011 the data was also collected from direction 2.

2.6 Data analysis techniques and software used

Most of the collected data was processed and analyzed using Road Doctor™ Pro software. The software enables the combining of GPR, HWD, lasers scanner, thermal camera, IRI, rutting and other data together with videos and maps. When all the data is linked together, an integrated data analysis utilizing comparisons and correlations between different factors affecting the road behavior can be made. The Road Doctor™ Pro software includes link to Elmod back calculation software, forward calculation module based on FHWA formulas and Swedish Bearing Capacity parameter calculation modules. The ROADEX Odemark dimensioning analysis, also built-in, was used for initial bearing capacity calculation.

The Swedish PMS Objekt software, based on linear elastic theory, was used in calculation of remaining lifetime and in strengthening design. “Elmod 6”, made by Dynatest, is software that can be used to back calculate the layer moduli values but also to make FEM analysis of stresses and strains in the road structure.

In this project, Bisar® software was used for deflection analysis and evaluation of axle loads heavier than 10 tons and for the evaluation and comparison of the different truck options. It is also based on linear elastic theory. Bisar® calculates the horizontal and the vertical stresses and strains induced to the different layers of the road structure using given loads. It also outputs the amount of horizontal and vertical displacement in selected points of the subgrade and structural layers.

3. The Surveyed Road Sections

Highway 4 is the main road leading through Finland from south in Helsinki to north in Utsjoki. The sections 505 and 515, chosen for the Barents project in Finnish Lapland, are located 15 km and 75 km north of Rovaniemi. The survey section 505 is 5,911 m and section 515 is 9,642 m long. The test section in 515 ends before an aircraft emergency landing strip starts.

Test section 505 starts at a small bridge. It travels across morainic soils and bedrock hills and later passes through long stretches with peaty and silty subgrade. The road geometry is generally good and there are no high hills or tight curves. Section has only one 15 m long bridge at 3,240 m. The section ends at Vikajärvi village at road 82 junction. In 2011 the average traffic volume (AADT) in this section was 3269 and the amount of heavy traffic was 320. The width of the section according to the road data base is 7,5 m, but according to laser scanner data the pavement width was 8 m.

The test section in road section 515 begins at Raudanjoki bridge. The main characteristic of this section is long straights. There are a few small hills, but the landscape is gentle and the curves are not tight. The section ends at the end of the aircraft emergency landing strip at 7,090 m. Compared to section 505 traffic volume is lower and AADT in this section was 1653 and the amount of heavy traffic was 169. The width of the section according to road data base is 8,5 m.

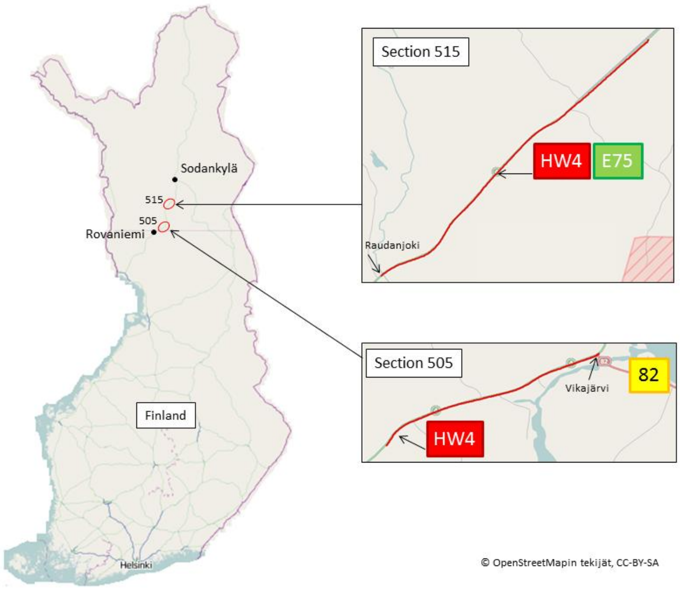


Figure 4. Location of Barents Finland test sections.

4. Structural and Functional Condition of the Road

4.1 Construction History

Highway 4 has a long history of connecting the villages and the city of Rovaniemi and the municipality of Sodankylä. Information regarding the construction history was found from the digital records of the Finnish Transport Agency.

According to these records, both test sections were gravel surfaced until the early 1960’s. First record of pavement on section 505 was found from 1971. In 1980 a new asphalt pavement AC was made. In 1991 sections with rut problems were treated with fine milling and a new AC layer was laid on the top. After that this section was treated using a remixer method in 2002. In 2008 – 2009 the road section started to suffer especially from top down cracking. In the spring, water was pumping through the pavement when the frozen road was thawing (figure 5). Based on pavement diagnostics, this section had light strengthening in 2010 and as result of this work the weakest sections ended up with a slightly thicker asphalt layer on the top.

Section 515 was paved for the first time with soft bitumen macadam (oil gravel) in 1963. After that it was repaved with the same material in 1979. In 1986 the section was rehabilitated and strengthened throughout. The old layers were spread to widen the road and a new thick layer of aggregate (base course and sub-base together) was laid as along with a new layer of asphalt concrete on the top. Finally in 1997 repaving was done by laying new layer of asphalt on the top.

Figure 5. Digital still images and thermal camera images from HW 4, road section 505 in spring 2009. Thermal camera data shows severe top down cracking problems close to the pavement surface. Colder areas in both wheelpaths indicate water pumping through the pavement.

4.2 Road Structures

Section 505 consists of about 200 mm of bound layers and another 200 mm of unbound base course. Steel reinforcements against frost cracking have been installed in several places and in many sections they were installed inside the bituminous layer. During the last strengthening in 2010, one new steel reinforcement section was made between 1480 – 1630 m. In that section reinforcement was installed in the bottom of the bituminous pavement layers. Base course thickness varies greatly. The average total thickness of the pavement structure was about 1,0 m.

The GPR data showed a very uniform structure throughout the other test section 515. Average thickness of the bound layers was 165 mm and average thickness of base course was 300 mm. The average total thickness of pavement structure was about 1,3 m, which means that the structures were much thicker than in section 505, even though 505 had more heavy traffic.

Table 1. The structure layer thicknesses in sections 505 and 515.

	Bound courses [mm]	Unbound base [mm]	Other unbound structure [mm]	Whole structure [mm]
Section 505				
min	91	56	151	511
max	343	479	2678	3075
average	193	178	582	952
Section 515				
min	70	50	266	709
max	413	612	2341	3165
average	165	319	847	1331

4.3 Subgrade Soils and their Effect on Road Performance

The distribution of subgrade and substructure moduli values is presented in figure 6 and detailed maps in Appendix 1. Based on the FWD analysis results the greatest part of subgrade and substructure moduli values belongs to class 40-80MPa. Road section 505 did not have any moduli values less than 20 MPa and only 1,1% subgrade moduli values were between 10-20 MPa. Stronger subgrade moduli values, higher than 120MPa, were measured in 5,1% of the length of section 505 and in 11,9% in road section 515.

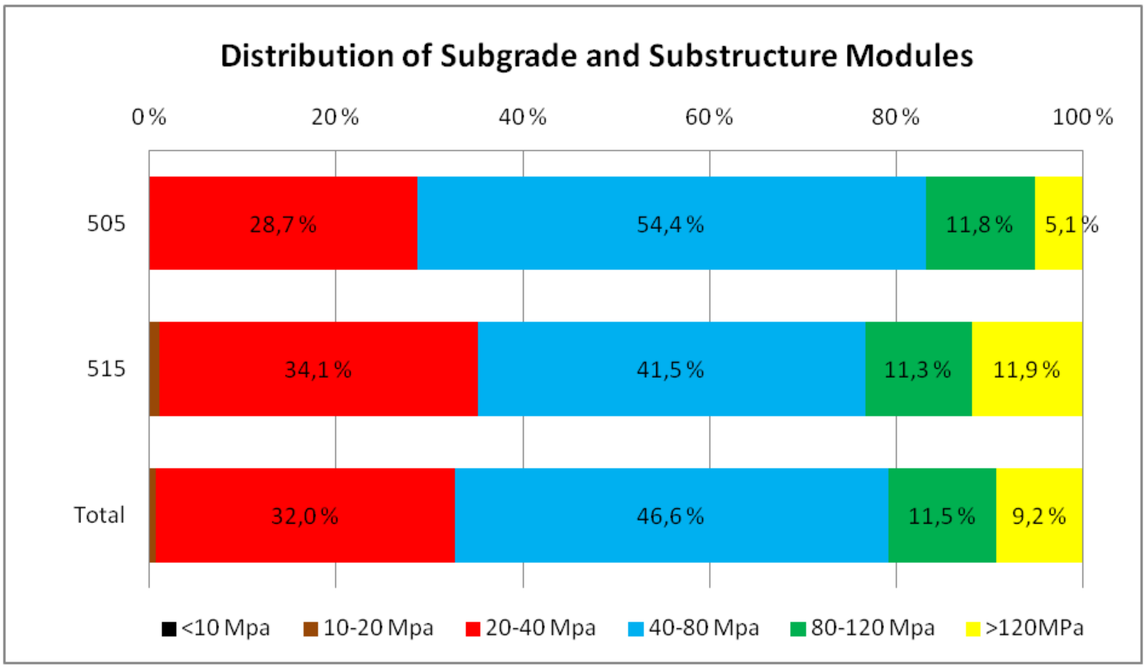


Figure 6. The distribution of subgrade modules in both road sections.

Subgrade and substructure module, higher than 80 MPa, tells that the material is strong and has a good bearing capacity (for example gravel, sand or coarse grained moraine). If the subgrade soil module would be less than 10MPa, the subgrade is very weak (for example peat and wet silt soils) and susceptible to Mode 2 rutting. Subgrade soils with moduli values 10-20 MPa are also quite weak and have great risk of losing their strength during the spring thaw period (for example clay, silt and moraine with high fines content). In surveyed road sections there were only a very small amount of values less than 20MPa.

4.4 Road Cross Sections

The road cross section was surveyed with GPR in many locations. In section 505, 14 cross sections were measured and in section 515 15 cross sections were measured. Some examples of cross sections from road section 505 are presented in figures 7, 8, and 9. In general, all of the cross sections displayed quite uniform structures in the top part of pavement structure. The old road had however suffered earlier from Mode 2 rutting. The presence of a relatively high number of steel grids indicates that the road has had frost heave problems.

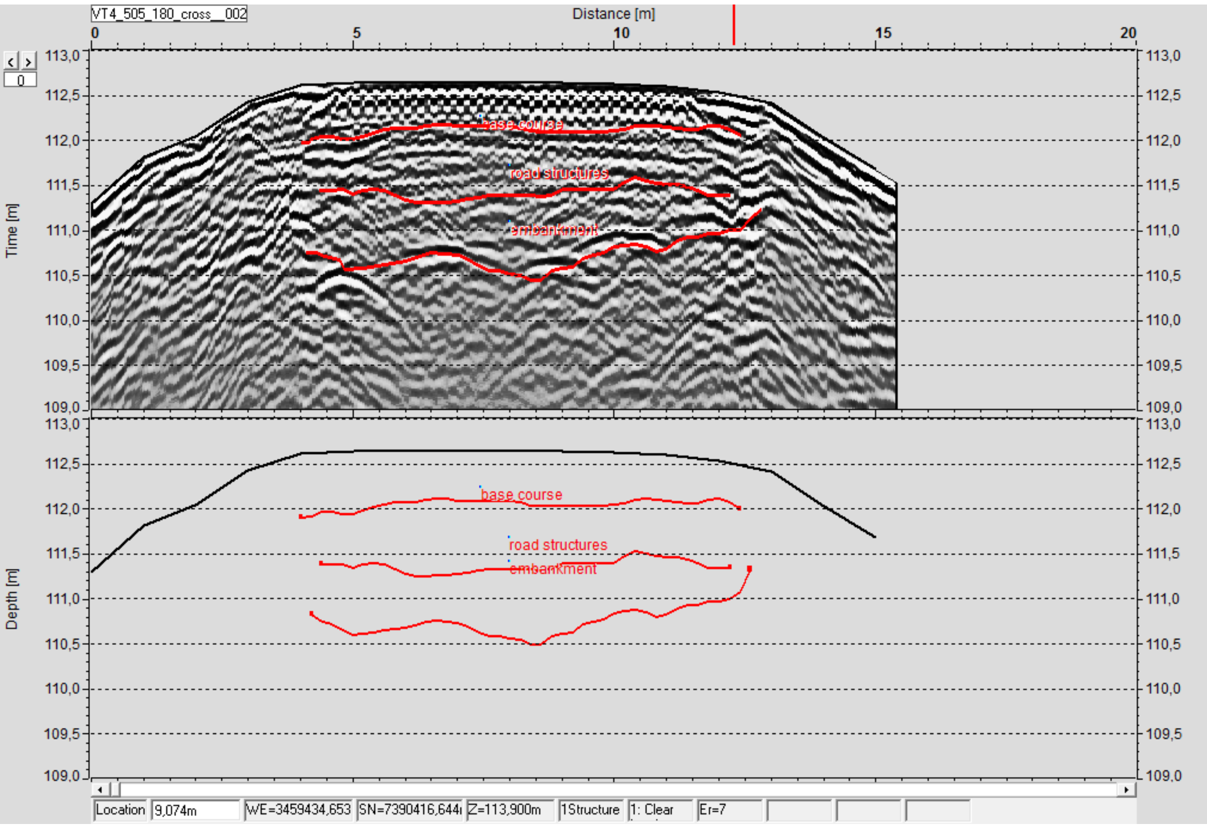


Figure 7. 400 MHz GPR cross section and its interpretation at chainage 180 m.

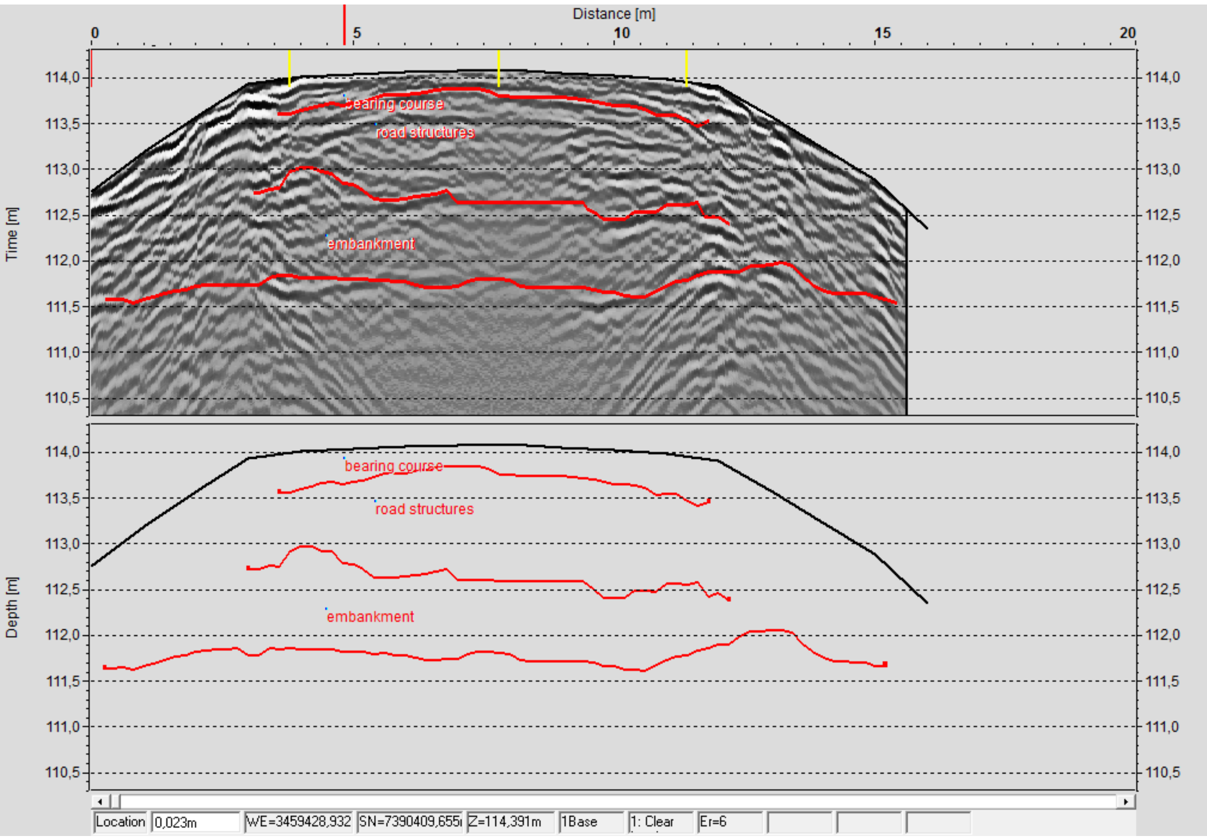


Figure 8. 400 MHz GPR cross section and its interpretation at chainage 2540 m.

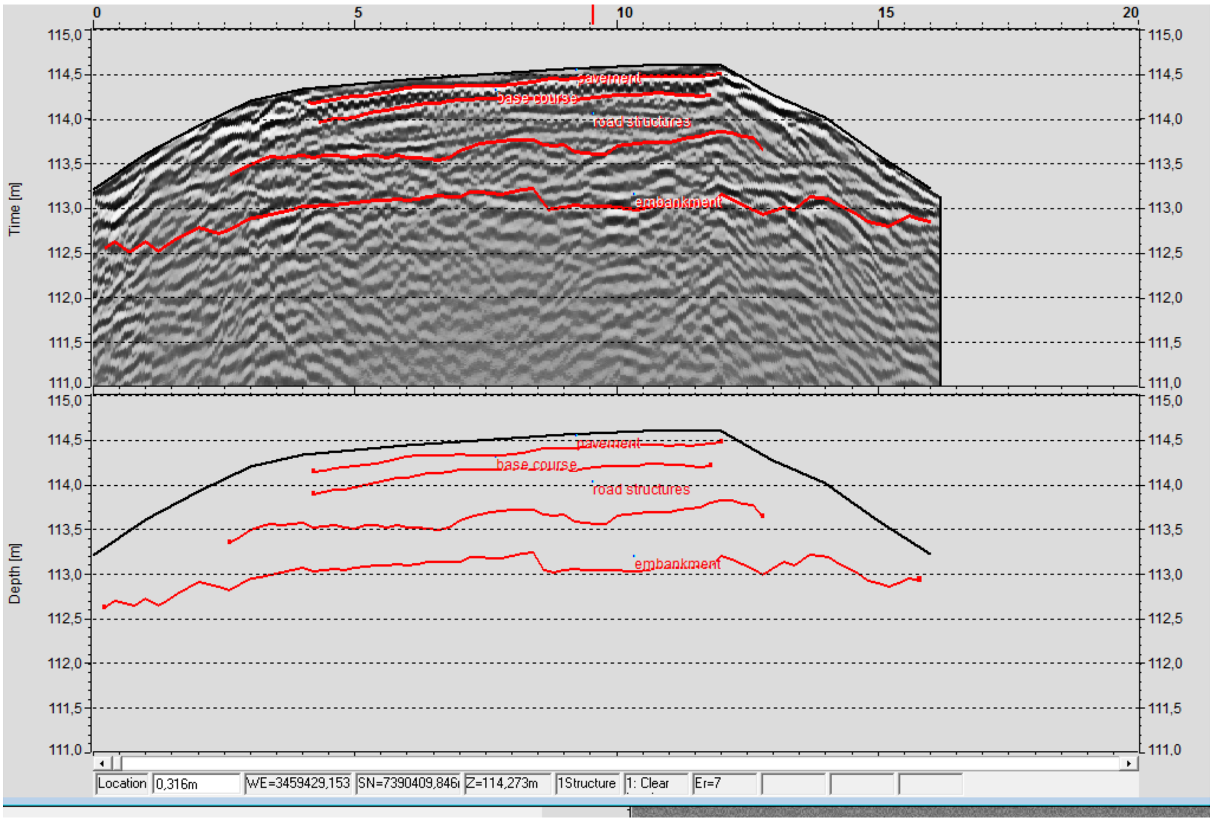


Figure 9. 400 MHz GPR cross section and its interpretation at chainage 3770 m.

4.5 Pavement Distress, Rutting and Roughness

4.5.1 General

Pavement distress types in this project were classified into nine different classes: deformation, longitudinal cracking, transverse cracking, edge breaks (left and right), alligator cracking, potholes, raveling and patches. Raveling and potholes however could not be found from these sections. The inventory was made visually on the road from a moving vehicle by inputting the distresses using a computer keyboard as they were seen on the road.

Table 2 presents the distress inventory summary statistics, shown as percentage values, calculated from the length of the sections. In section 515, pavement inventory was done up until the beginning of the emergency aircraft landing section at 7120 m.

Table 2. Results of pavement distress inventory.

Section	Deformation (%)	Longitudinal cracking (%)	Transverse cracking (%)	Alligator cracking (%)	Edge breaks, right (%)	Edge breaks, left (%)	Patches (%)
505	0,4	4,2	2,1	0,5	1,7	0	0
515	0,4	12,1	4,1	28,4	4,4	9,3	0,06

4.5.2 Section 505

As described earlier, section 505 received a new pavement in 2010 so at the time of the analysis the pavement was only one year old. Despite this, narrow and new, and mainly frost related, transverse cracks could be detected over the whole section (figure 10). Some single longitudinal cracks could be found mainly at the end of the section (figure 10).

Figure 10. Section 505, direction 1: Left photo: 350 m. Differential frost heave related transverse cracks on side sloping ground. Right photo: 3200 m. Frost action related longitudinal cracking before the bridge.

Since section 505 has new pavement, the roughness (IRI, 10 m) value in the right wheel path is low in both directions, mainly less than 3 mm/m. Higher peaks occur at the same places as transverse cracking. When the roughness (IRI) values of direction1 from the year 2011 was compared to the results of the years 2008 – 2009, the data showed that even though the IRI values in 2011 are lower, the peaks of the highest values are at the same places as before.

Figure 11 shows the rut depths in summer 2011 on both sides of section 505.The maximum rut depth was less than 10 mm in the right lane and in the left lane 10,2 mm were the highest values. The average rut depth was 2,9 mm in the right lane and in the left lane, the average value was higher, 4,3 mm. The difference between the directions is notable and can be explained by the differences in the amount of heavy traffic. A slight increase appears at the beginning of the section and at the end of the section. In the left lane, there are several places, where the rut depth is 5 – 10 mm. In the right lane, the rut depth is less than 5 mm. At the beginning and at the end of the section, on side sloping ground and on embankment, there are a couple of short sections, where the rut depth is 5 – 10 mm.

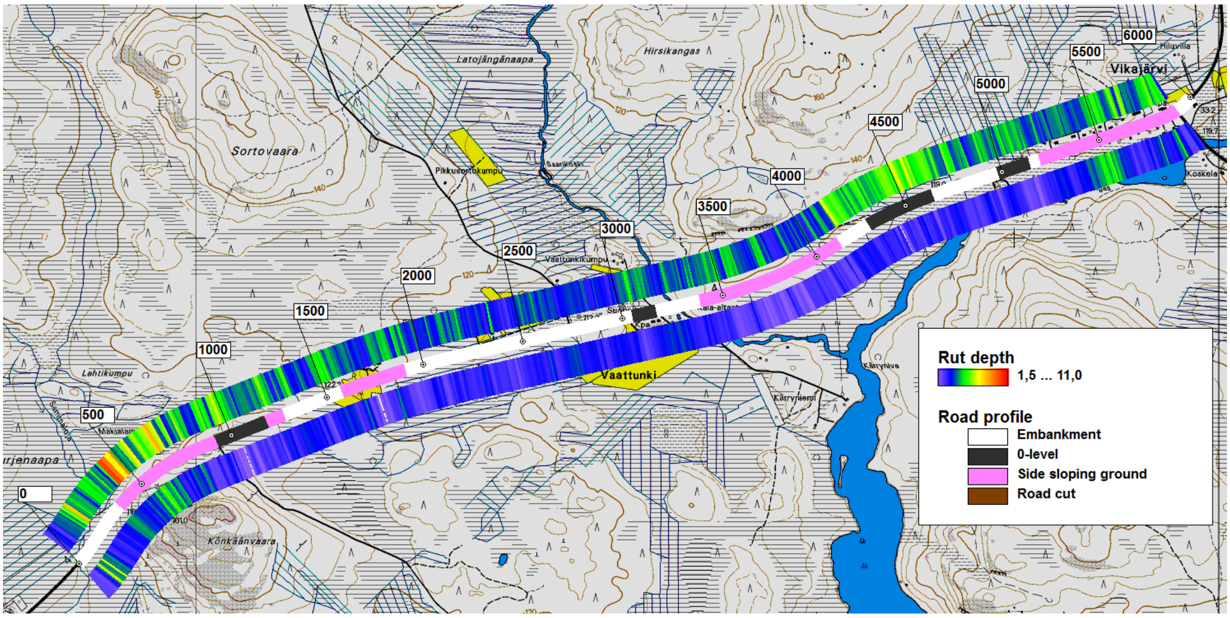


Figure 11. Rut depth in the right lane (direction 1, right) and in the left lane (direction 2, left) in section 505. The road profile is in the middle.

4.5.2 Section 515

In section 515, more pavement distresses occurred than in section 505. The pavement distresses types that were found most were alligator, transverse and longitudinal cracking (table 2, figures 12 and 13). Most damaged sites appear between 1000 – 2500 m, 3000 - 5000 m and from pole 6000 to the end of the study section (figure 13).

Figure 12. Section 515, direction 1: Left photo: 4000 m. Longitudinal, transverse and alligator cracking. Right photo: 4460 m. Longitudinal, transverse and alligator cracking.

Figure 13. Section 515, direction 2: Left photo: 7000 m. Patch on the middle of the road. Right photo: 4360 m. Transverse cracking and left edge break.

The roughness history values (IRI, 10 m) in the right wheel path show, that there has not been any growth between the years 2008 – 2011. The roughness values are mainly less than 3 overall in right lane. The growth of roughness during the years 2008 - 2011 is also low. In summer 2011, the roughness values (IRI, 10 m) were also measured from the left lane. These values are mainly less than 4 mm, but there are some peaks higher than that. At the end of the section (5900 – 7120 m), the IRI values rise a bit higher than elsewhere in the left lane (figure 14). In the same section the greatest amount of longitudinal cracking was detected indicating that roughness problems are frost action related.

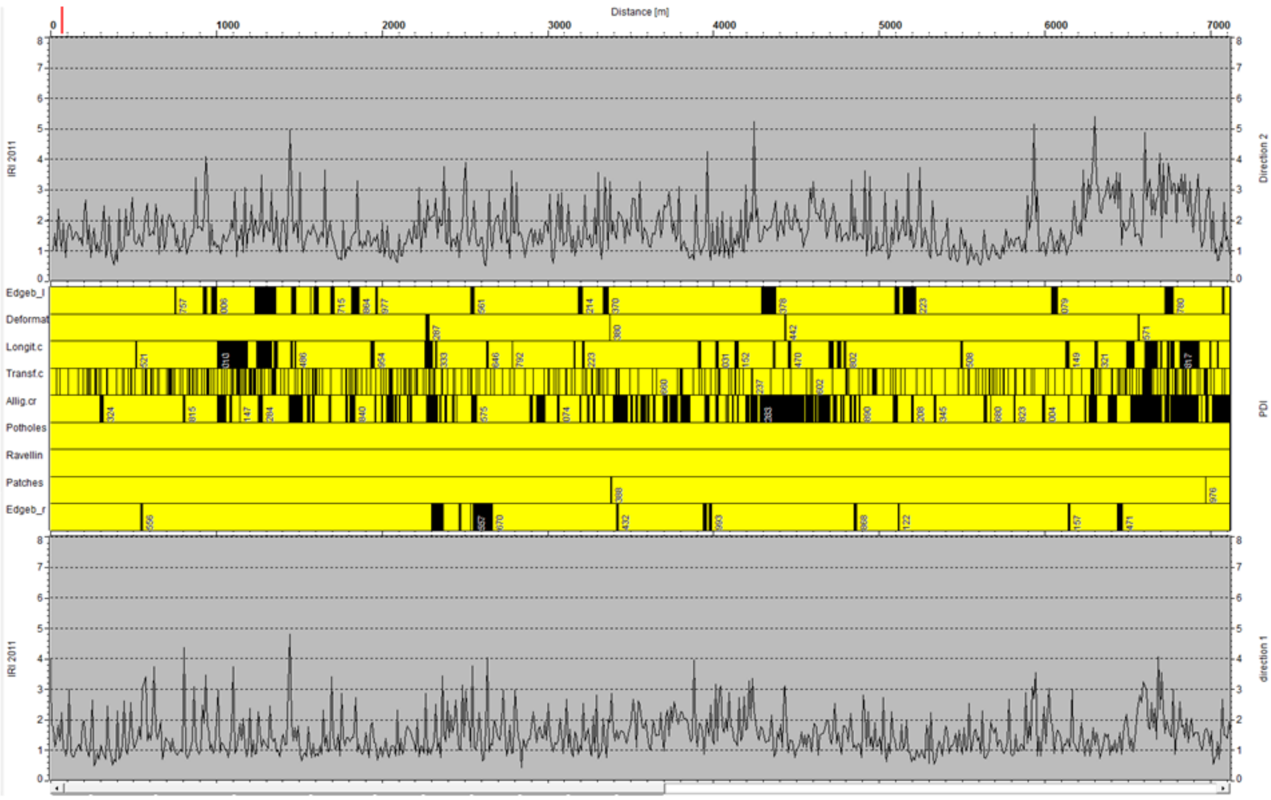


Figure 14. The roughness (IRI, 10 m) values of the right lane (lowest) and left lane (topmost). The pavement distress inventory is shown in the middle.

When the maximum rut depths (direction 1) from the year 2011 were compared to the results of 2008 – 2010, they seem to be increasing, but mainly they are still less than 10 mm. In the right lane, the average is a bit smaller, 5,9 mm and in the left lane, the average rut depth is 6,7 mm. There are two places, in the middle of the section and at the end of the section, where the maximum rut depth is higher than elsewhere (figure 15). In the left lane, rut depth values are high at the same places as in the right lane, but there are several places, where the maximum rut depth is more than 10 mm. Within the sections in the middle and at the end, the pavement has several distresses and drainage is in poor or adequate condition.

In the right lane, the growth of the rutting was calculated from the maximum rut values of the years 2008 - 2011. The growth is mainly less than 1 mm in the whole section. Only in the middle of the section, where the rut depth values are highest, the growth of rutting is more than 1 mm. This indicates that there are no serious permanent deformation problems in this road section. On the whole, it seems like the growth of rutting in section 515 has stabilized.

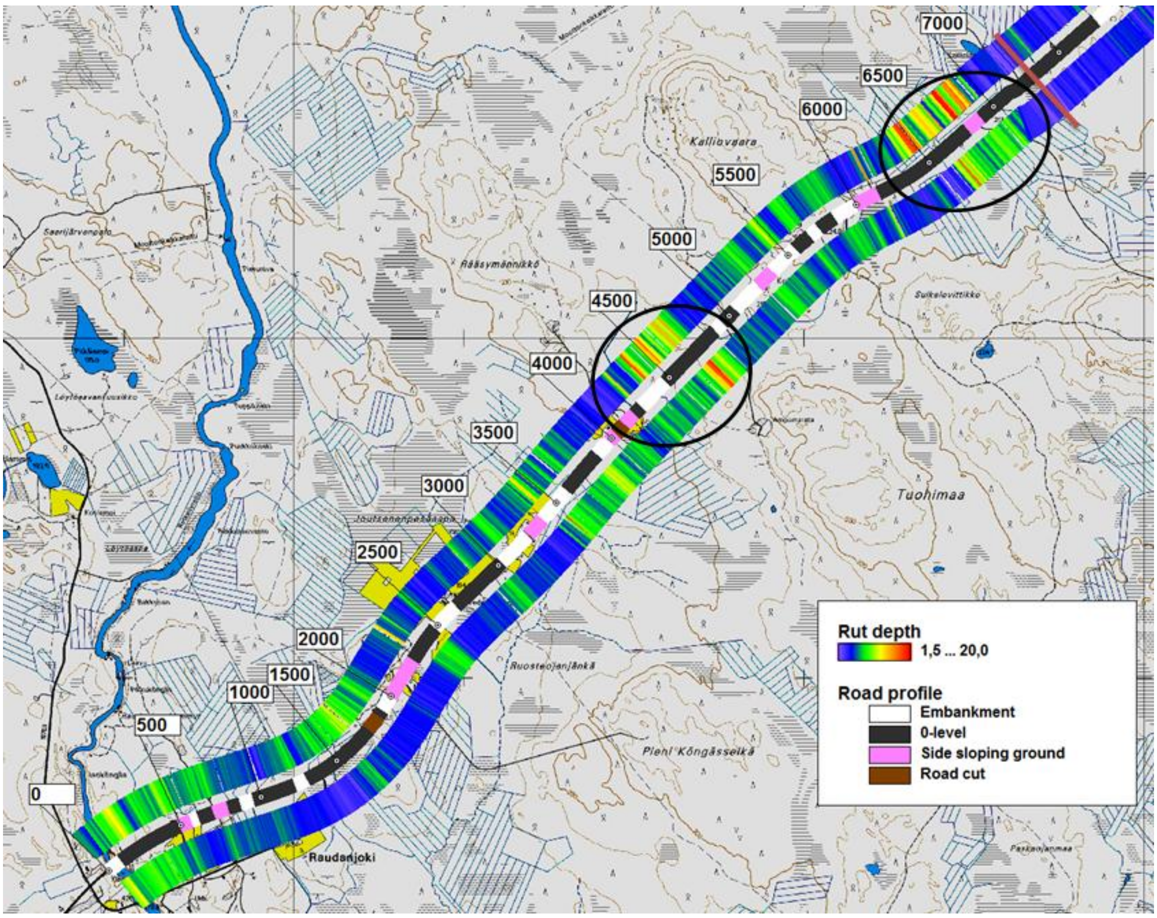


Figure 15. Rut depth in the right lane (direction 1, right) and in the left lane (direction 2, left) in section 515. The road profile is in the middle. The worst places are marked with circles. The supplementary aerodrome begins at the red line.

4.6 Bearing Capacity and risk for Mode 1 and Mode 2 rutting

The Odemark bearing capacity was calculated using the ROADEX Odemark method. The bearing capacity was good in both road sections. The greatest part of bearing capacity values were more than 400 MPa, 68,1% in road section 505 and 84,6% in road section 515. The weak section in road section 505 is from 4000 m to 5700 m, where the bearing capacity is 300 – 400 MPa. In road section 505 the weakest section is from 900 m to 1100 m, where the bearing capacity is 200-300 MPa. In road section 515 there are only a few short sections where the bearing capacity is 200-300MPa. Mainly the bearing capacity in road section 515 is mainly higher than 400MPa. The distribution of bearing capacity is presented in figure 16 and detailed maps in Appendix 2.

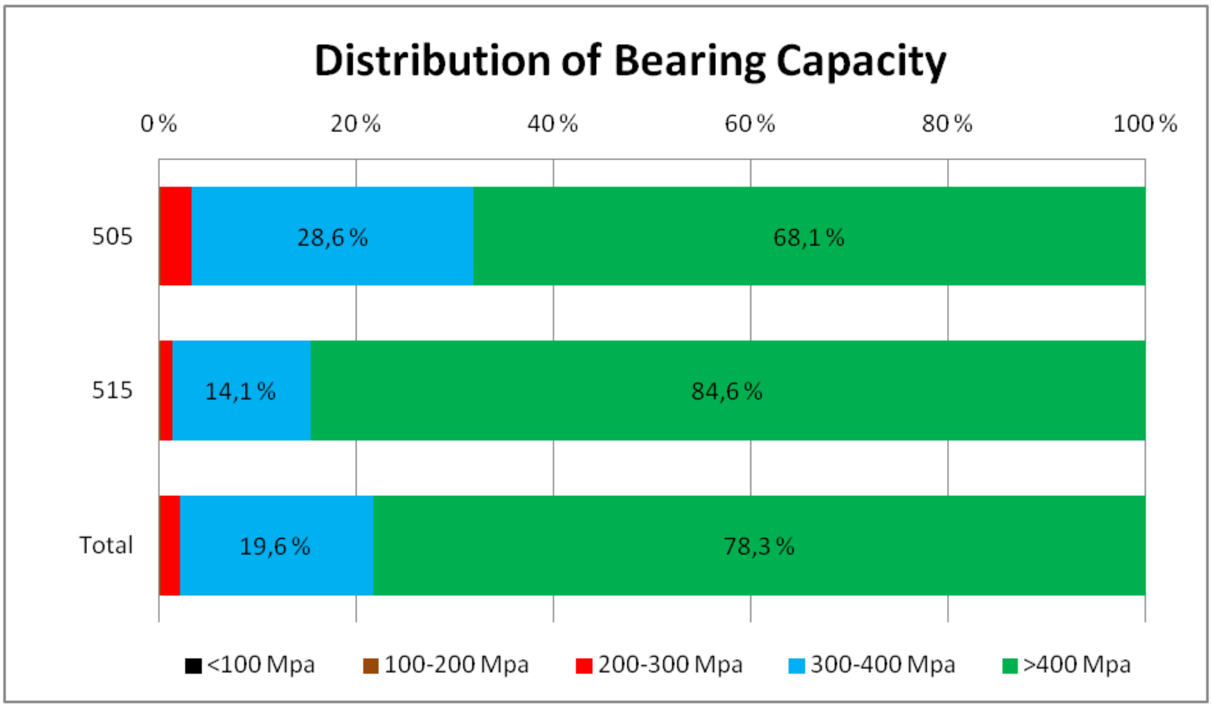
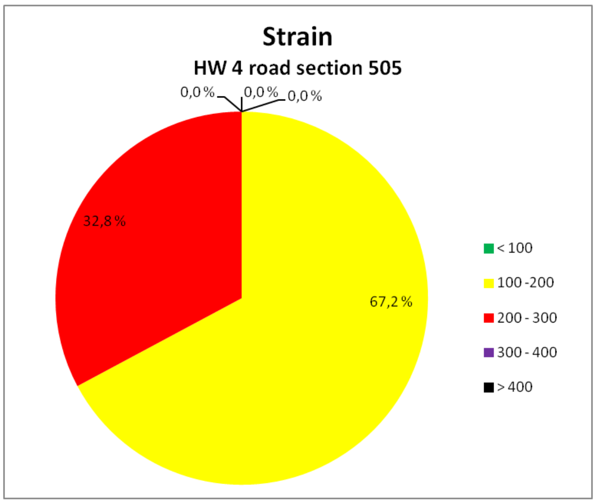


Figure 16. The distribution of bearing capacity in both road sections.

In this impact and risk analyses the strain values of pavement were also calculated. The strain values calculated from the bottom of the bound layers were used as an indicator of risk for Mode 1 rutting. The strain values are quite low in both road sections indicating that the risk form mode 1 rutting is low. In section 505 67,2% and in section 515 54,9 % of strain values are less than 200. The distribution of strain values are presented in figure 17 and detailed maps in Appendix 3. Another indicator for Mode 1 rutting is SCI value and the calculated SCI values are also quite low. The distribution of both sections is presented in figure 18.



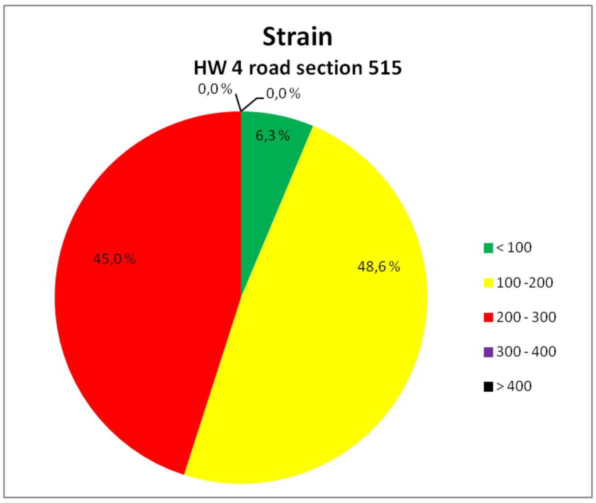


Figure 17. The distribution of strain values in both road sections.

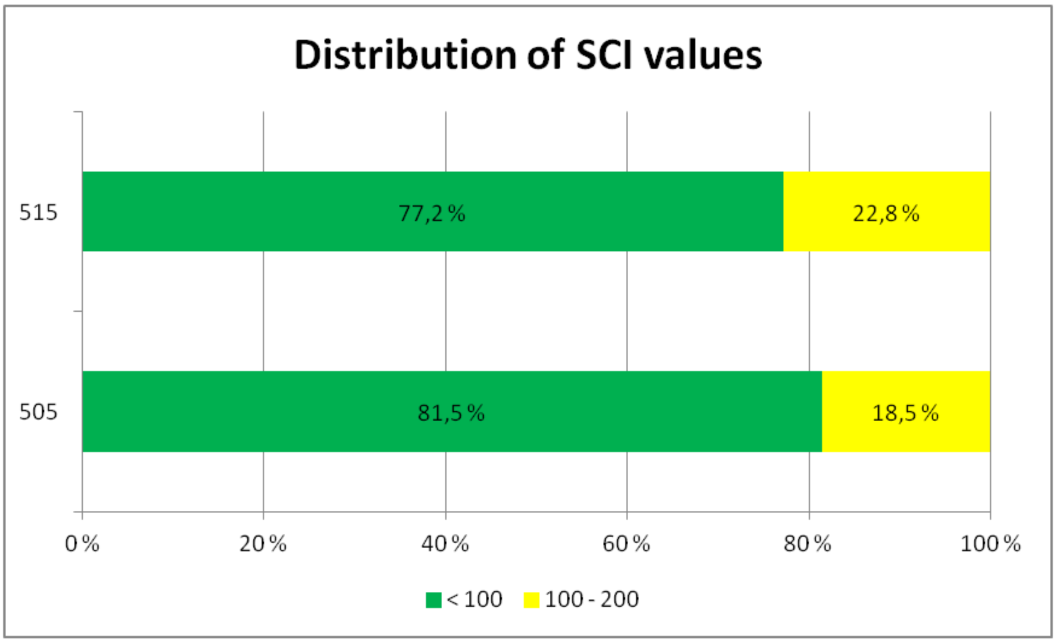


Figure 18. The distribution of SCI values in both road sections.

The indicator for Mode 2 rutting is BCI (base curvature index) value. In general the BCI values are also quite low. There are only few short sections with high (>40) BCI-values. The distribution of BCI values of both sections is presented in figure 19.

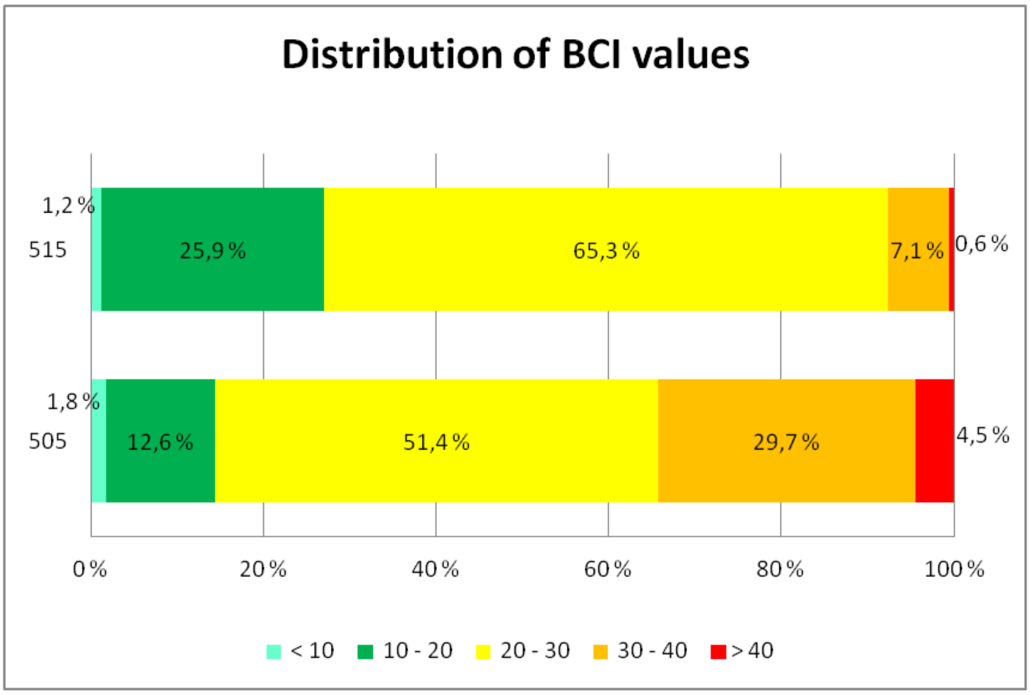


Figure 19. The distribution of BCI values in both road sections.

4.7 Frost Related Problems

From section 505, it was possible to use a frost heave data and a point cloud video showing frost heave in pavement surface. From the videos the places where frost heaves occurred can be seen. The laser scanner data, depth of the ditches and interpretation of the GPR data were compared to one another to find out what has caused the frost heaves.

One of the main causes of frost heaves in section 505 was private exit roads blocking water flow. This kind of problem occurred for instance at private exit roads at chainage 950 m and at 1750 m (figure 20) and in Vikajärvi village. The primary cause of the frost heaves in this area, however, is that the bottom level of side ditch is higher than the bottom of the road structure as shown in figures 21 and 22.

Frost analysis also showed that the higher rutting and IRI values in the left lane cannot be attributed completely to the higher amount of heavy traffic in left lane heading towards Rovaniemi. Frost heave was also higher in the left lane because the road is located mainly on side sloping ground that slopes from left to right. Another finding of this analysis was that better drainage maintenance would have a major effect on decreasing frost damage, increasing bearing capacity and in increasing pavement lifetime. These maintenance measures would also be economically very profitable to road owner.

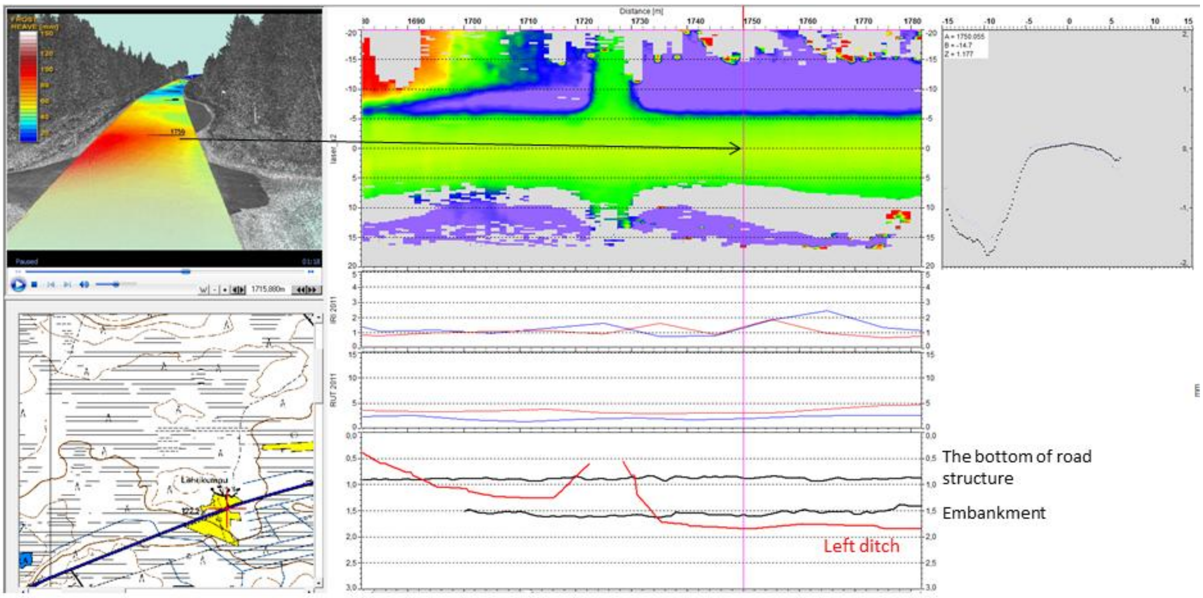


Figure 20. Frost heave analysis at chainage 1750 m. Top left field shows the frost heave point cloud video and bottom left field the map of the area. The windows on the right side, from top to down are: laser scanner data as a surface level color map from left lane (direction 2), the roughness (IRI) values from the right lane (blue line) and left lane (red line), the rut depth from the right lane (blue line) and left lane (red line); the fourth window shows in meters the depths of the ditch (red line left ditch), the bottom of the road structure (topmost black line) and the bottom of the embankment (the lower black line). The window in the upper right shows the cross section from the left ditch from the point marked with red line. The analysis shows that left ditch is deeper than the embankment bottom level and the laser scanner data shows, that there is nothing blocking water flow in the ditch. Thus the reason for the problems is that the private exit road culvert has become clogged or it is frozen in the winter and it blocks the water flow causing the frost heaves on the road. The IRI values have started to rise in both lanes.

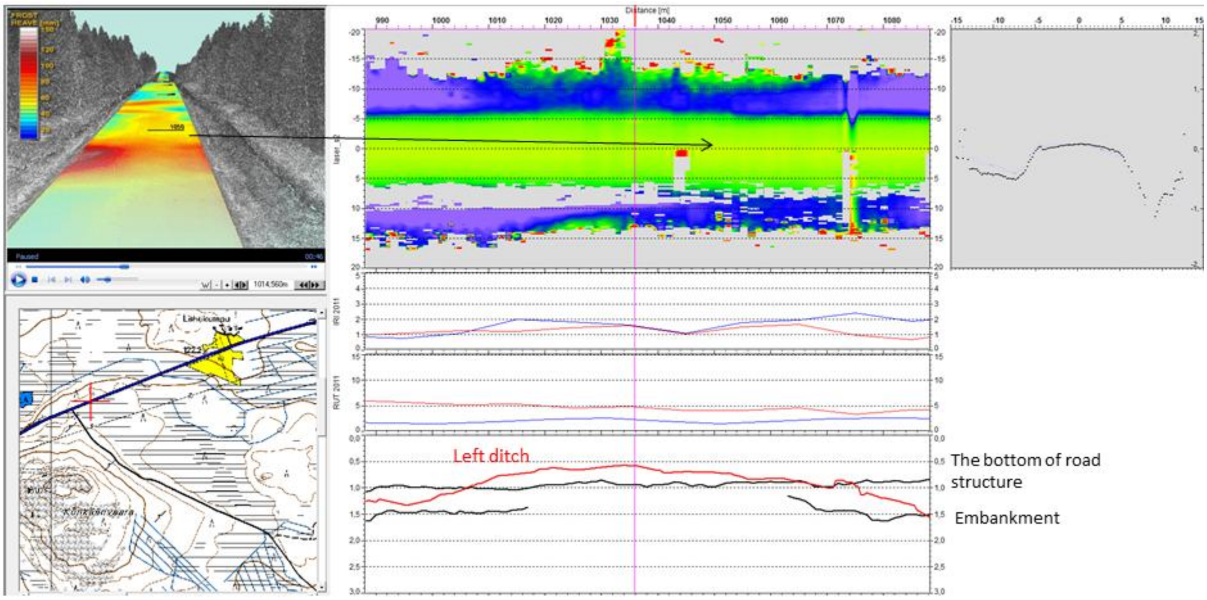


Figure 21. Pole 1050 m. A too shallow left ditch has blocked the flow of water causing frost heaves and transverse cracking in the road. The ditch bottom is higher than the bottom structure of the road and water can flow into road structure. The roughness values have risen in the right lane and the rut depth has started to grow in the left lane. The explanations for data in this figure are the same as for the data in figure 20.

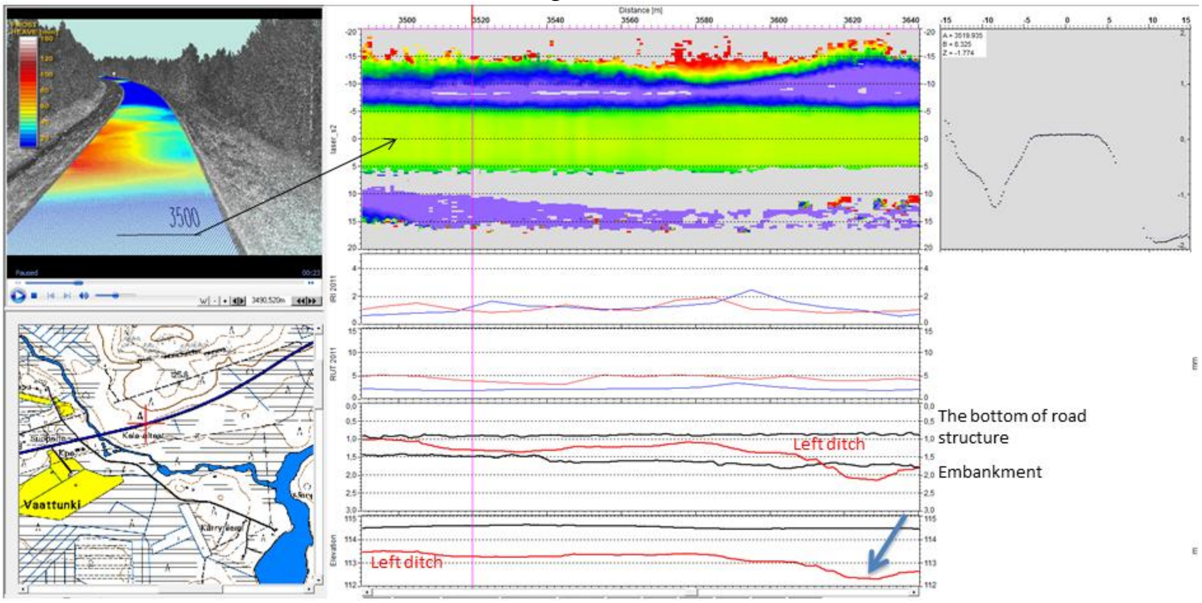


Figure 22. On the side sloping ground the frost heaves occur at pole 3500 m and the IRI values in both lanes and the rut depth in the left lane have started to grow. The bottom of the ditch is deep enough compared to the bottom of road structure. The fifth window in the middle shows the elevation of the road (black line) and the left ditch (red line). This shows that there is a pit in the ditch at pole 3520 m (marked with red, vertical line) and flow of water to the downhill side is blocked causing frost heaves. There is a culvert (marked with blue arrow) at pole 3610 m and water should flow towards it. The explanations for the data in the figure are the same as in figure 20.

4.8 Drainage Analysis

4.8.1 Section 505

In drainage analysis the drainage condition was divided into three different classes: Class 1 good condition, Class 2 adequate condition and Class 3 poor condition. The overall survey statistics from section 505 are shown in figure 23. These statistics also show that the left side of the road was more problematic compared to the right side.

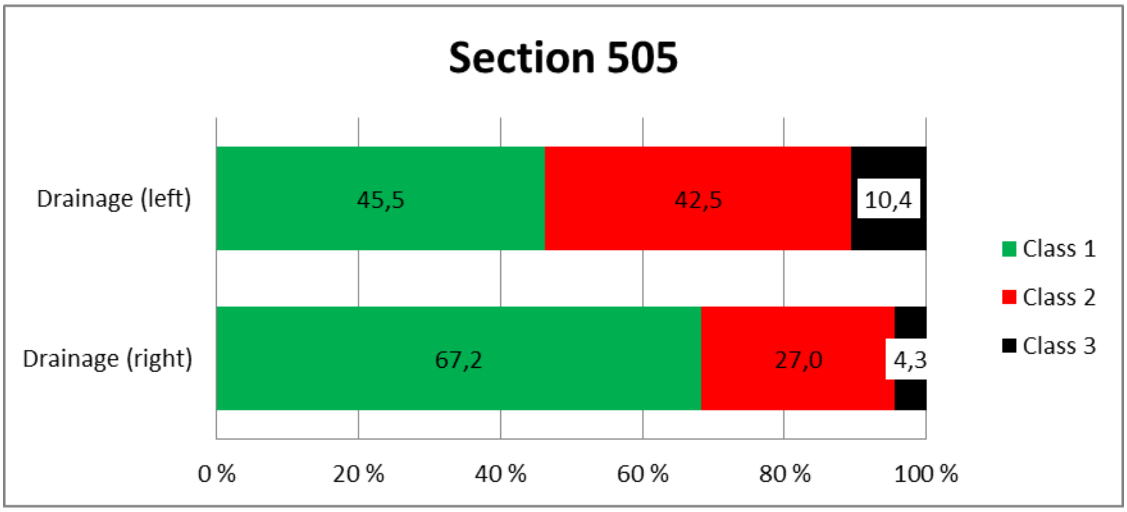


Figure 23. Distributions of drainage class in both ditches of the highway 4 at section 505.

One of the reasons the drainage was classified as adequate or poor class in section 505, was that the vegetation blocked the ditches. At the beginning and at the end of the section, on side sloping ground, there were places, where the ditch was not deep enough or a private road exit blocked the flow of water as frost analysis showed. Some of the ditches had been repaired recently (e.g. 4200 – 5000 m, left ditch), but landslides had blocked some of them. The places where the drainage was classified as being in poor condition are mostly on shallow embankments (figure 24). In road section 505, all the outlet ditches are working properly.

The average drainage condition was poorest in embankment sections, in both directions (figure 25), but still average value was less than 2. On 0-level, the drainage is as good in both directions and on side sloping ground in direction 2, the drainage is worse than in direction 1.

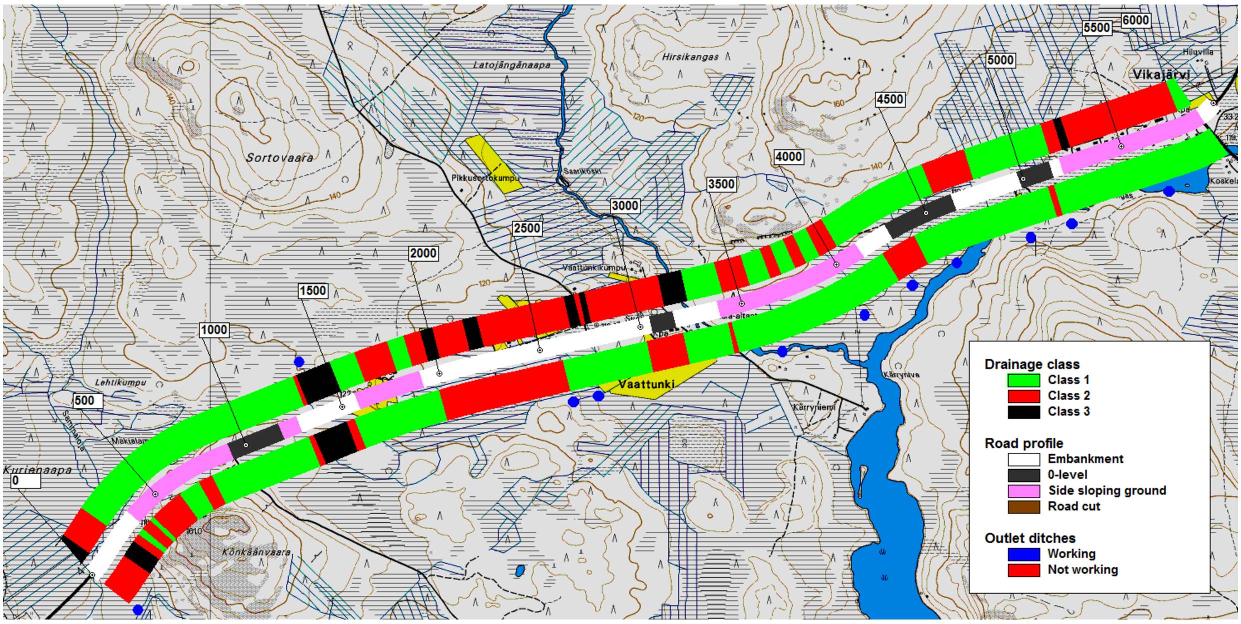


Figure 24. Distribution of the drainage class in section 505. On the left, drainage condition of the left ditch and on the right, drainage condition of the right ditch. Outlet ditches are marked as dots. The road profile is shown in the middle.

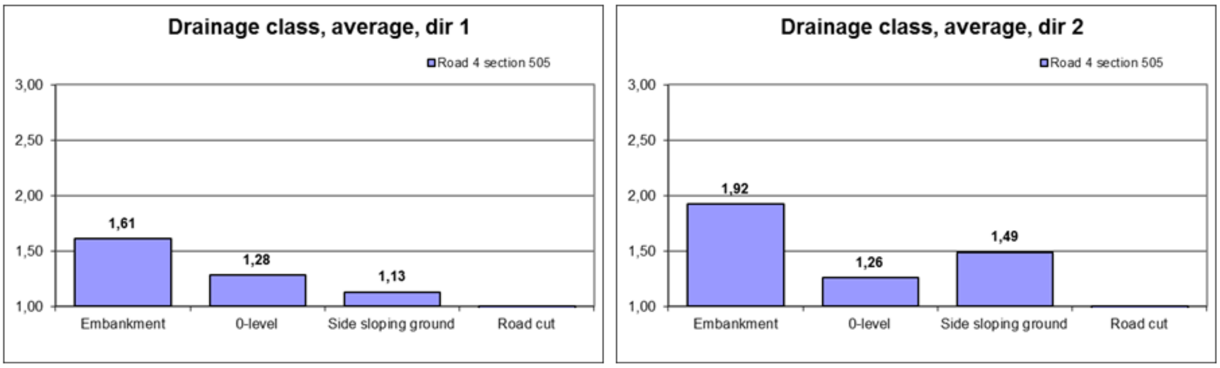


Figure 25. Average drainage for each road profile in direction 1(left) and in direction 2 (right). There were no road cut sections in 505.

There were no major differences between the average roughness (IRI) or rut depth values from different road profiles and the directions. The average rut depth on embankment and side sloping ground is as high in direction 1, but in direction 2 the average rut depth is a bit higher on side sloping ground.

4.8.2 Section 515

The overall drainage survey result statistics from section 515 are shown in figure 26. The figure shows that average drainage is much worse in this section compared to road section 505.

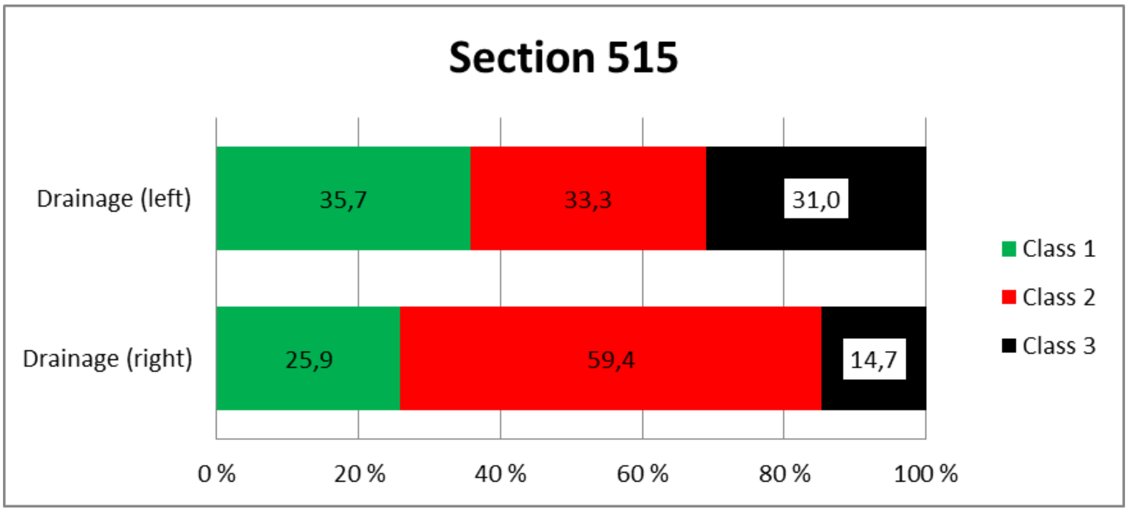


Figure 26. Distributions of drainage class in both ditches of the highway 4 in section 515.

In section 515, drainage is mostly in poor condition in the places where the road crosses swamps and road is on 0-level (figure 27). When comparing the results of the pavement inventory and drainage, it is worth noting that the most damaged stretches of section 515 are the same as those with poor drainage. Within these sections, the maximum rut values are also the highest. In road section 515 the drainage on the left side is in worse condition. The ditches in poor condition were shallow and blocked by vegetation.

In direction 1, there was only one ditch (1440 m) of the seven that was not working (figure 27). On the left side of the road, there was only one nonfunctioning ditch.

The majority (54,6 %) of the road profile in section 515 was classified into 0-level and only 2,5 % into road cut. In both directions, the drainage is in worse condition on 0-levels (figure 28).

Roughness (IRI) and rut depth values were compared to the road profiles on both sides and there were no major differences. The highest average roughness is in road cuts. In both directions, the average rut depth is highest on 0-level and the lowest in road cuts (figure 29).

Figure 30 shows that average roughness (IRI) values clearly become higher in both directions as the drainage class gets worse. This indicates that poor drainage has a major effect on frost action and differential frost heave also in section 515. However the average rut depth (figure 31) does not correlate as well as with the drainage classes as IRI does but rut depths in drainage class 3 are clearly higher than in class 1 and 2.

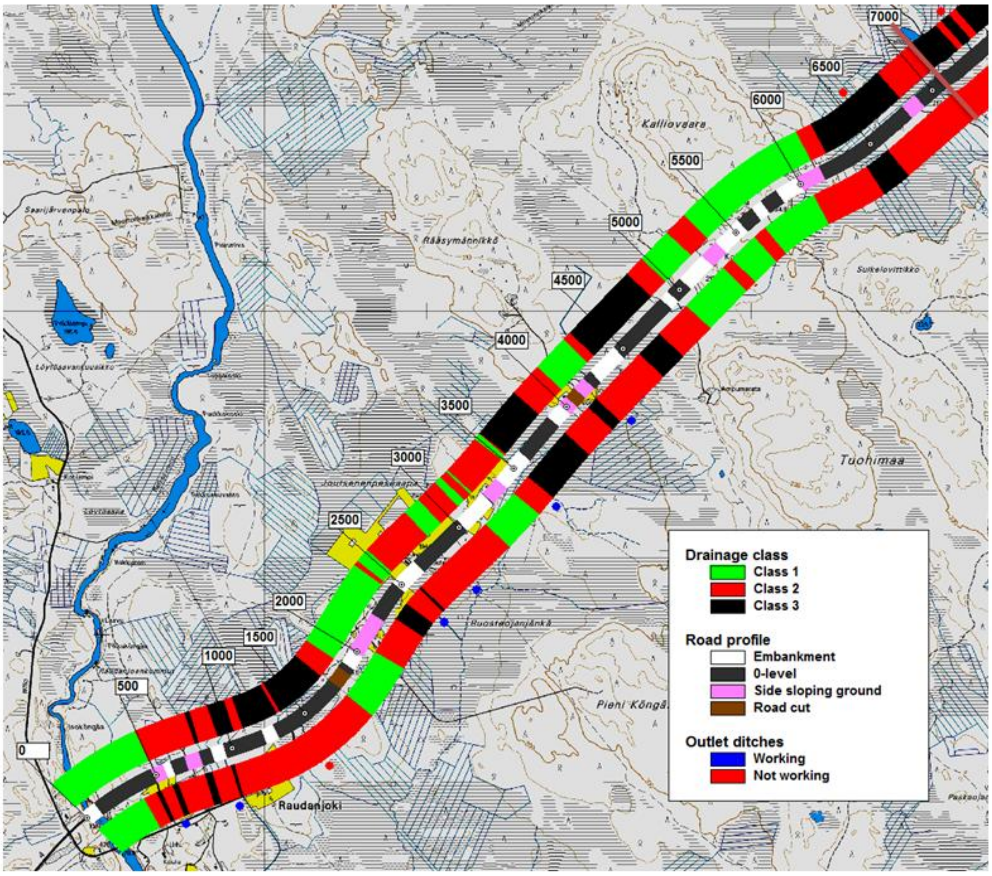


Figure 27. Distribution of the drainage classes in section 515. On the left, drainage condition of the left ditch and on the right, drainage condition of the right ditch. Road profile is shown in the middle. Outlet ditches are marked as dots. The supplementary aerodrome starts at the red line and extends towards the north.

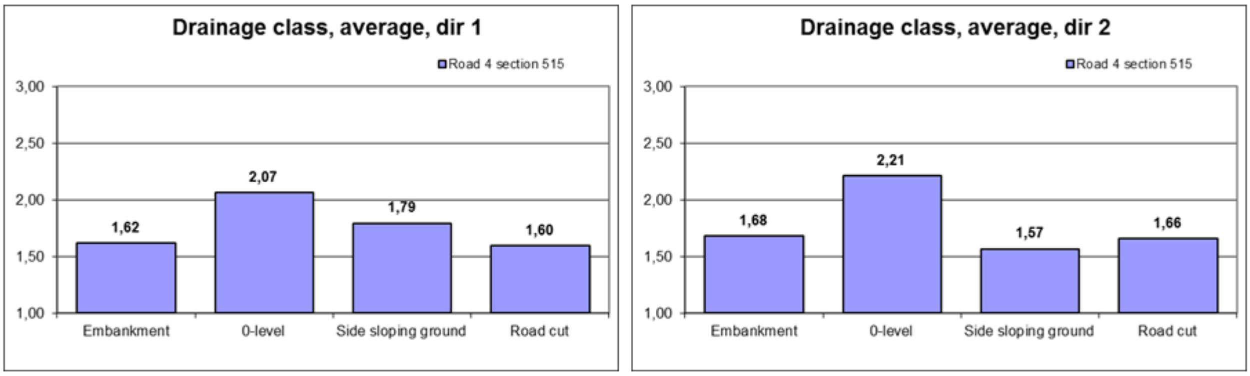


Figure 28. Average drainage for each road profile in direction 1(left) and in direction 2 (right).

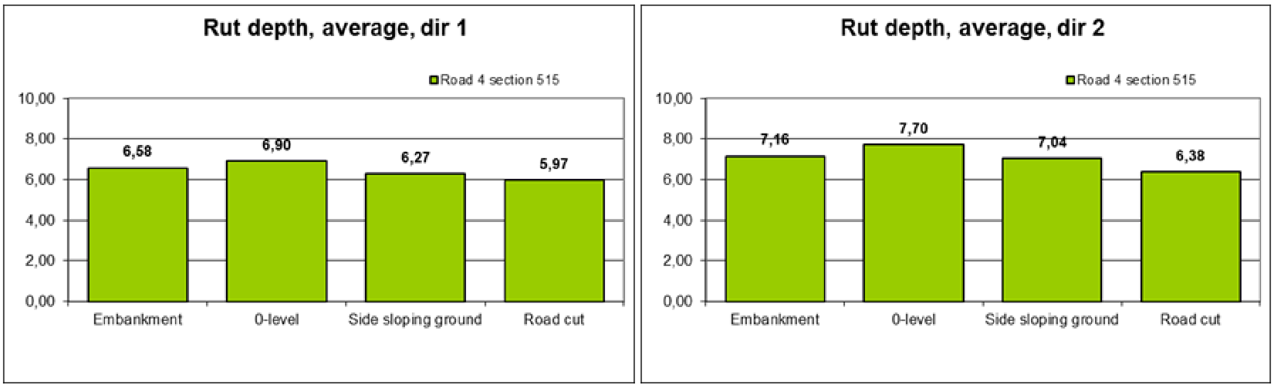


Figure 29. Average rut depth for each road profile in direction 1(left) and in direction 2 (right).

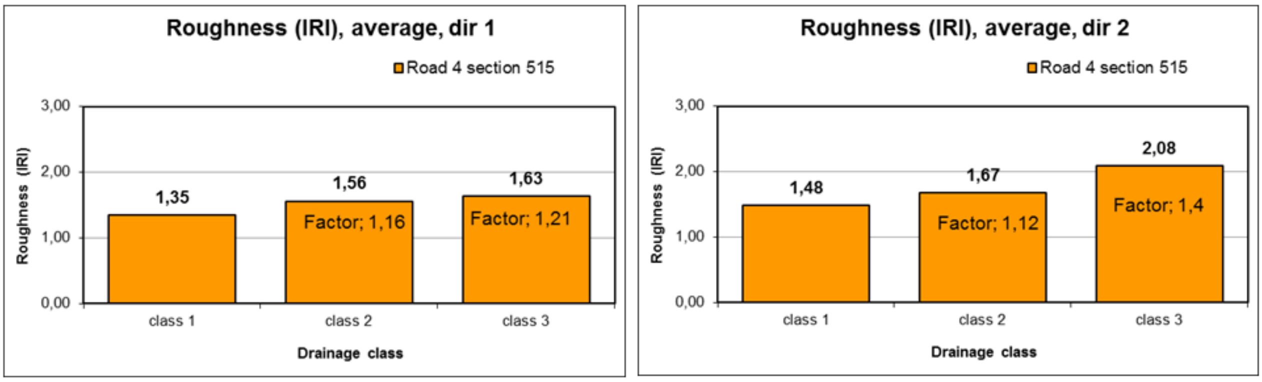


Figure 30. The average IRI values in direction 1 (left) and in direction 2 (right) for each drainage class. The factor inside the column shows how many times larger the value is compared to the value for Class 1.

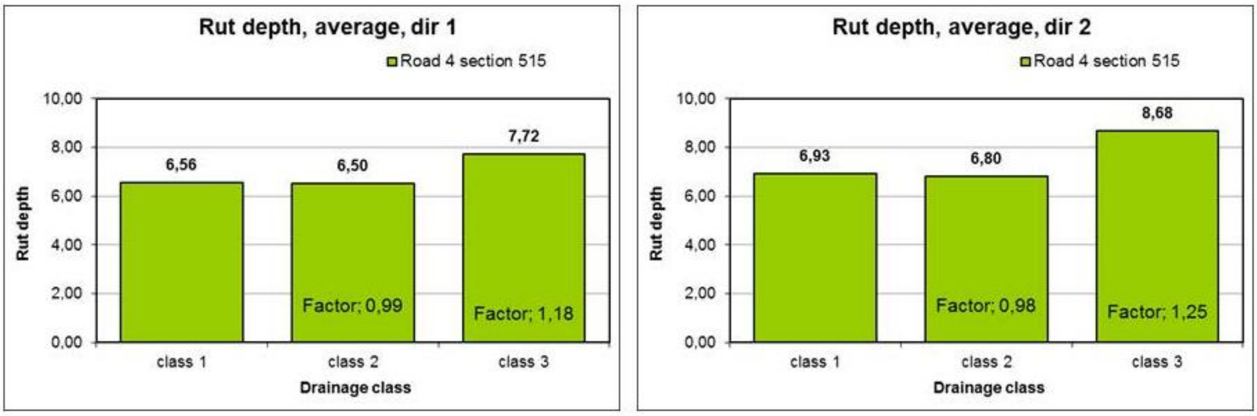


Figure 31. The average rut depth value in direction 1 (left) and in direction 2 (right) for each drainage class.

4.9 Potential Geotechnical Problems

Both surveyed road section are in quite good condition. Sections with potential for geotechnical problems were not detected.

5. Risk analysis, pavement life time and need for strengthening

5.1 Risk Classification and Design Principles

In the first design process, both road sections were divided further into risk classes according to the evaluations of the road condition based on, among other things, GPR data and FWD data.

<u>The risk classification was done according to following principles:</u>

- <u>Risk class 1:</u> Strong road section, no major risk for immediate failures. Pavement fatigue will follow normal road lifetime prediction models.
- <u>Risk class 2:</u> Relatively strong road. Road damage will appear quickly only in extreme loading conditions or due to poor drainage maintenance etc. Strengthening is still recommended for this class.
- <u>Risk class 3:</u> Adequate road section. The risk will mainly develop during particularly bad spring thaw weakening periods. Strengthening is still also recommended for this class.
- <u>Risk class 4:</u> Weak road section. High risk for road failures especially during the spring thaw weakening period. Strengthening strongly recommended.
- <u>Risk class 5:</u> Extremely weak road section. Severe damages can be predicted immediately after heavy haulage starts – should be strengthened immediately.

Layer thickness values were printed at 5m intervals and each structure section was examined statistically. For the PMS Objekt analysis, road structures were defined based on the worst quarter limit (lowest value at which thickness falls with thinnest25%). The structure thickness values were defined from the GPR-data taken from the left line closest to the right wheel path.

The PMS-objekt® software was used to calculate bearing capacity and remaining lifetime of the initial structure. In addition, calculations were made to define the strengthened structure, which would reach the theoretical 20 years lifetime both in the bottom of bound layers (Mode 1 rutting) and in subgrade/road structure interface (Mode 2 rutting). The calculations were made for current and increased traffic volumes with current truck options (60 ton).

After the strengthening structure was planned using PMS Objekt® to the level of theoretical lifetime expectancy of 20 years, new calculations were started with BISAR® software in order to analyze the impact of heavier (72 and 90 ton) truck options on the weakest structures in both road sections.

With BISAR® the stresses and strains in the road structure were calculated at the following most critical points of the road structure in order to evaluate the development of distresses and permanent deformation:

1. The horizontal tensile strain at the bottom of the bound layers
   - High values of strain indicate a risk of pavement fatigue.
2. The vertical compressive stress and strain at the upper part of the unbound layers
   - The stresses and strains in this position are the most critical for the development of Mode1 rutting, i.e. rutting in the base course layer.
3. The vertical compressive stress and strain on the top of the subgrade
   - The stresses and strains in this position are the most critical for the development of Mode2 rutting, i.e. rutting in the subgrade.

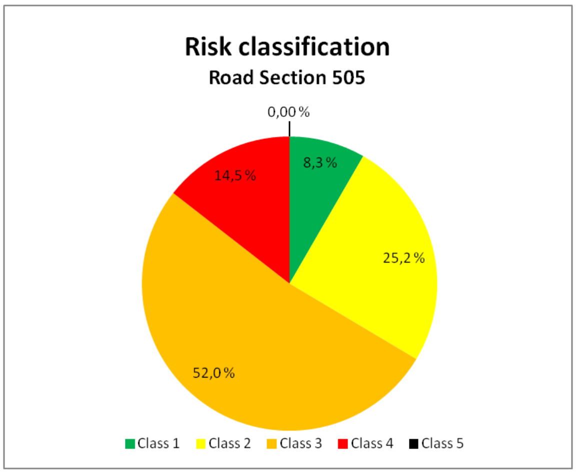
Special interest was focused on the displacement of weak subgrade under different truck configurations. With BISAR® software the subgrade displacement was calculated for the heaviest (the dimensioning) axle group of each truck option. For each truck option the cumulative effect of the consecutive axles or axle groups on the subgrade displacement was also calculated.

The impact of heavier truck options on pavement performance was also evaluated using "fourth power rule" calculation and also strain results from the BISAR® calculations.

Finally, based on the impact analysis, it was evaluated if additional road strengthening would be needed for the heavier truck options.

5.2 Risk classification

The analysis showed that the greater portion of road sections 505 and 515 belongs to risk class 3 (52,0% of section 505 and 44,2% of section 515). Risk class 5 was not found in either section. The distribution of risk classes is presented in figure 32 and detailed maps in Appendix 4.



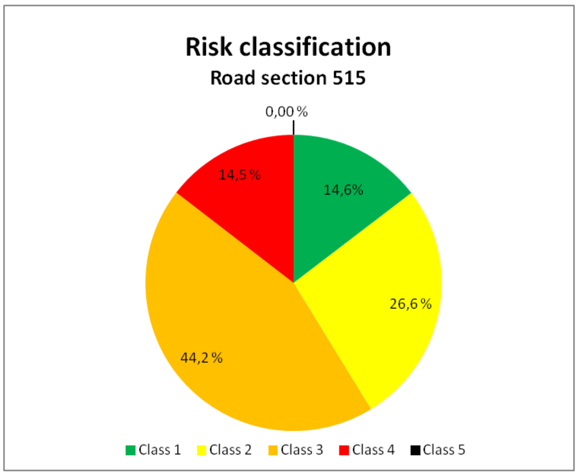


Figure 32. Distribution of risk classes in road sections 505 and 515.

5.3 Remaining Lifetime of Current Road

The calculations of remaining lifetime of the current road were made with Swedish PMS Objekt software. In these calculations the road was divided into subsections based on measured FWD and GPR data. The thickness values, which were used in PMS Objekt-calculations, were chosen according to the third quarter limit (thickness value presenting the limit for the thinnest 25%) from GPR data measured from the right wheel path.

The results showed that the remaining lifetime of the current road is quite good/long at the foundation level (table 3). In risk classes 1, 2 and 3 (both road section 505 and 515) the lifetime at the foundation level would be more than 20 years. In road section 505, in risk class 1, the lifetime of bound layers would also be more than 20 years. In the other risk classes the remaining lifetime of the bound layers varies from 4 years to 19 years. The remaining lifetime of bound layers is naturally shorter in 515 compared to section 505 which was recently paved.

Table 3. The remaining lifetimes of each risk class with initial traffic.

505	Initial traffic		515	Initial traffic	
Risk class	**Bound**	**F oundation level**	**Risk class**	**Bound**	**Foundation level**
1	>20	>20	**1**	5	>20
2	18	>20	**2**	4	>20
3	19	>20	**3**	14	>20
4	7	7	**4**	9	13

5.4 Increased Traffic Volume with Current Truck Options

The options with increased traffic volumes were defined based on hypothetical situation whereby the volume of heavy traffic increases 50%, 100% or 200% (table 4) with current truck options (60tn trucks). As a point of comparison it can be stated that, in the scenario where all trucks are fully loaded, if the transportations were to increase by 1 million ton per year, it means that the volume of heavy traffic would increase by 72 vehicles (total volume of heavy trucks is 392 on road sections 505 and 241 on road section 515). If the transportations would increase by 5 million tons per year, it means that volume of heavy traffic would increase by 361 vehicles (total volume of heavy trucks is 681 on road sections 505 and 530 on road section 515).

Table 4. The total traffic volumes and amount of heavy traffic with different options.

	Initial		Heavy traffic +50 %		Heavy traffic +100 %		Heavy traffic +200 %	
Section	**Total**	**Heavy**	**Total**	**Heavy**	**Total**	**Heavy**	**Total**	**Heavy**
505	7960	320	8120	480	8280	640	8600	960
515	1653	169	1738	254	1822	338	1991	507

The calculations of remaining lifetime if the volume of the heavy traffic with 60tn trucks would increase were also made with PMS Objekt software according to the same principles that were presented in previous chapters. The results (table 5) showed that in road section 505, the remaining lifetimes are in risk classes 1, 2 and 3 at the foundation level more than 20 years in each scenario. The most critical part is risk class 4.

Table 5. The remaining lifetime of each risk class of road section 505 with different heavy traffic options.

505	Heavy traffic +50%		505	Heavy traffic +100%		505	Heavy traffic +200%	
Risk class	**Bound**	**Foundation level**	**Risk class**	**Bound**	**Foundation level**	**Risk class**	**Bound**	**Foundation level**
1	17	>20	**1**	13	>20	**1**	8	>20
2	12	>20	**2**	9	>20	**2**	5	>20
3	14	>20	**3**	10	>20	**3**	7	>20
4	5	5	**4**	4	4	**4**	3	2

The results in the road section 515 (table 6) showed that, in risk classes 1, 2 and 3 the remaining lifetimes at the foundation level are also more than 20 years although the heavy traffic volume would increase. The most critical part is risk class 4.

Table 6. The remaining lifetime of each risk class of road section 515 with different heavy traffic options.

515	Heavy traffic +50%		515	Heavy traffic +100%		515	Heavy traffic +200%	
Risk class	**Bound**	**Foundation level**	**Risk class**	**Bound**	**Foundation level**	**Risk class**	**Bound**	**Foundation level**
1	3	>20	**1**	2	>20	**1**	2	>20
2	3	>20	**2**	2	>20	**2**	1	>20
3	9	>20	**3**	7	>20	**3**	5	>20
4	6	9	**4**	5	7	**4**	3	4

Structural solutions were designed and tested based on PMS-Objekt software with a goal of designing a structure with a lifetime of 20 years. In road section 505 repaving is an adequate operation both for initial structure and with increased traffic volume in risk classes 1, 2 and 3. With initial traffic in risk class 1 no operations are needed. In risk class 2 and 3 new overlays would be needed (table 7 and figure 33). Biggest operations would be needed in 505 in risk class 4. In that section old pavement needs to be removed and in its place 1200-300mm of unbound base, 100-125mm of bound base and 100mmm of new pavement would be needed (table 7 and figure 34).

In road section 515 the repaving seems to be enough to increase the lifetime in each risk class. The thickness requirements for the new pavement vary from 30mm to 100mm (table 8 and figure 35).

Table 7. The rehabilitation recommendations for road section 505.

505	Initial traffic			Heavy traffic +50%		
Risk class	Pavement	Bound base	Unbound base	Pavement	Bound base	Unbound base
1	-			30mm	-	-
2	30mm			40mm	-	-
3	30mm			40mm	-	-
4	100mm	100mm	100mm	100mm	100mm	100mm

505	Heavy traffic +100%			Heavy traffic +200%		
Risk class	Pavement	Bound base	Unbound base	Pavement	Bound base	Unbound base
1	40mm			50mm	-	-
2	50mm			65mm	-	-
3	50mm			65mm	-	-
4	100mm	125mm	100mm	100mm	125mm	300mm

Table 8. The rehabilitation recommendations for road section 515.

515	Initial traffic	Heavy traffic +50%	Heavy traffic +100%	Heavy traffic +200%
Risk class	**Pavement**	**Pavement**	**Pavement**	**Pavement**
1	50mm	65mm	75mm	90mm
2	50mm	65mm	75mm	100mm
3	30mm	40mm	50mm	60mm
4	40mm	50mm	65mm	80mm

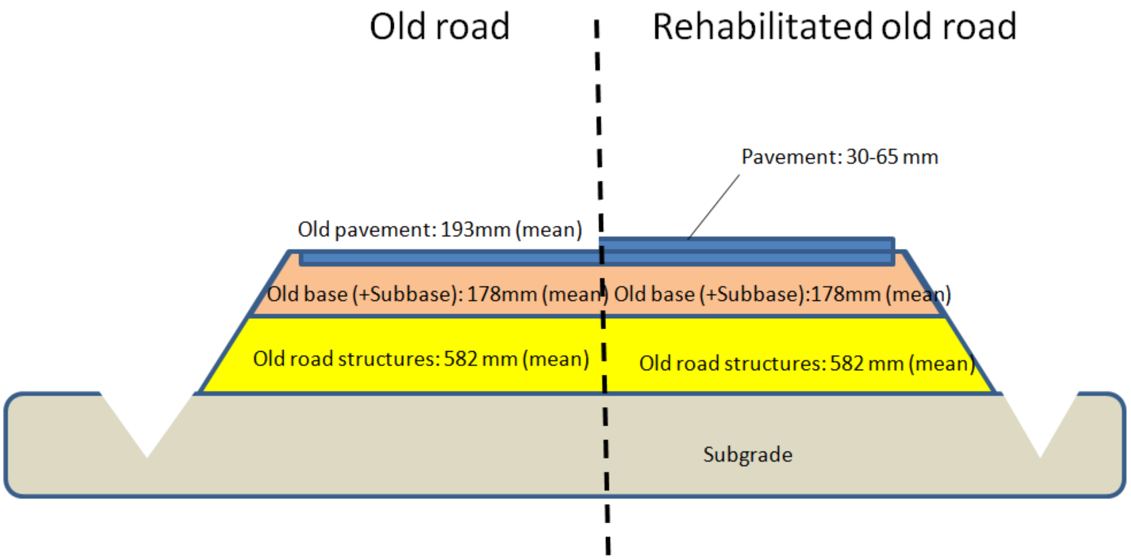


Figure 33. Strengthening structure for risk class sections 1, 2 and 3 in road section 505.

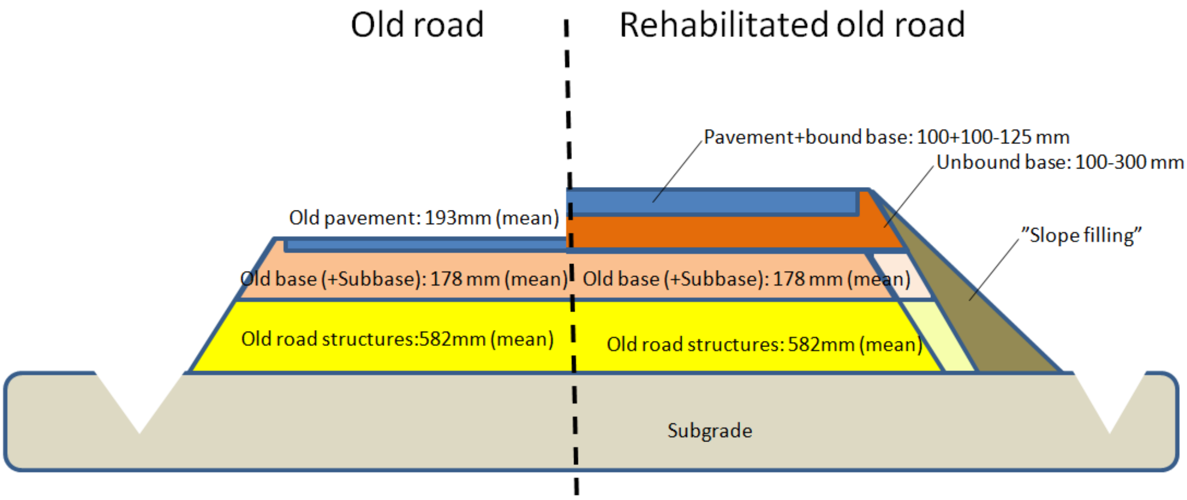


Figure 34. Strengthening structure for risk class section 4 in road section 505.

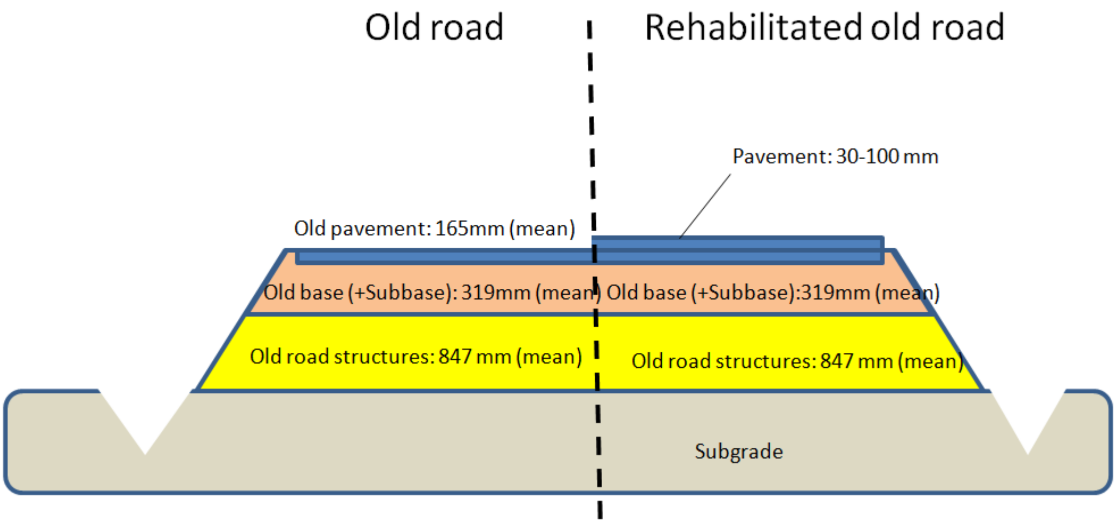


Figure 35. Strengthening structure for risk class section 1-4 in road section 515.

6. Risk Analyses and Structural Requirements with Heavier Trucks

6.1 General

Previous evaluations on the performance of the road structures with current heavy traffic volume as well as with increased heavy traffic volumes were made for the standard 60 ton truck option. In the next phase, the effect of two heavier truck options (72 ton and 90 ton) were evaluated and compared with the standard truck. Table 9 presents the net weights of each truck option and also the number of extra trucks per day if the total annual transportation would increase by 1 million or 5 million tons.

Table 9. The net weights of each truck option and the number of extra trucks per day if the total annual transportation would increase by 1 million or 5 million tons.

		+1 mill. tn/year	+5 mill. tn/year
Truck (tn)	Net weight (tn)	extra trucks/day	extra trucks/day
60	38	72	361
72	49	56	280
90	60	46	228

The analysis of pavement responses under the different loading options was made using multi-layer linear elastic modeling approach implemented in the software tool BISAR®. The approach is generally accepted worldwide and a very extensively used method to analyse the mechanical behavior of various types of pavement structures. In multi-layer linear modeling the pavement structure is described using a set of layers resting on top of each other and underlain by an elastic half space representing the subgrade. In the model both thickness and stiffness of each layer can be selected freely so as to enable as close a resemblance to the original structure as possible. In the meantime, tire loads resting on top of the road surface can also be modeled, one by one, by means of spherical contact areas on which an evenly distributed vertical pressure, corresponding to the tire inflation pressure, is acting.

As an output of the BISAR® analysis stresses, strains and displacements in different directions at selected points inside of the pavement structure and subgrade are obtained. For the present purpose the most interesting result is the vertical displacement on top of the subgrade which can be used as a convenient indicator of overall severity of the loading action caused by a vehicle that is stressing the pavement structure.

An inherent limitation of the multi-linear elastic modeling approach is that the loads are not moving but each of them is acting on a constant point. Therefore, the model cannot be directly used in assessing the visco-elastic behavior of soft and wet subgrade materials in which excess pore water pressure may develop under repeated loading as discussed later in this chapter. Another well-know limitation of the method is associated to thin pavement structures, typical for low volume roads, having only a thin bitumen bound layer as the wearing course. In the case of the analyses presented hereafter the limitation is, however, not important because both thickness of bound layers and the overall thickness of the analysed pavement structures are reasonably high.

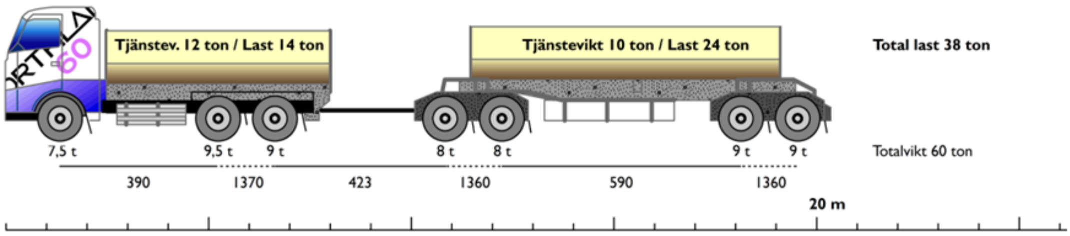
The tire type used in the evaluations was selected to be dual tire, because the experience from ROADEX project and a number of other earlier analyses have shown that dual tires are much more road friendly compared to super single tires. The stresses and strains in the top part of the road structure are likely to rise too high, if super single tires are used. Accordingly, the final tire type selection, to be used in the calculations, was dual tire with normal (800 kPa) tire pressure.

6.2 Different Truck Options

The two heavier truck options used in the calculations were "Boliden" 72 ton truck and "En trave till" (one stack more) 90 ton truck. These options were chosen, because both of them are already used in special applications in Sweden and are more or less ready alternatives for the standard truck. The standard 60 ton truck option was obviously analysed as well.

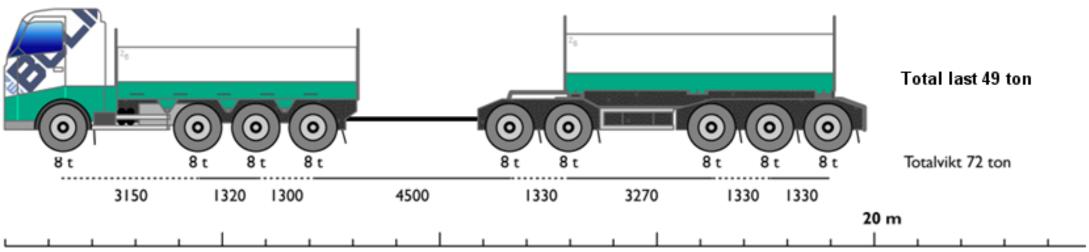
Standard 60 ton truck

A combination with 7 axles, three on the truck and four on the trailer. The dimensioning (critical) load used for the calculations is 9,5 + 9 ton double bogie. Total weight of the combination is 60 tons and net load 38 tons. Total length of the combination is 20 m.



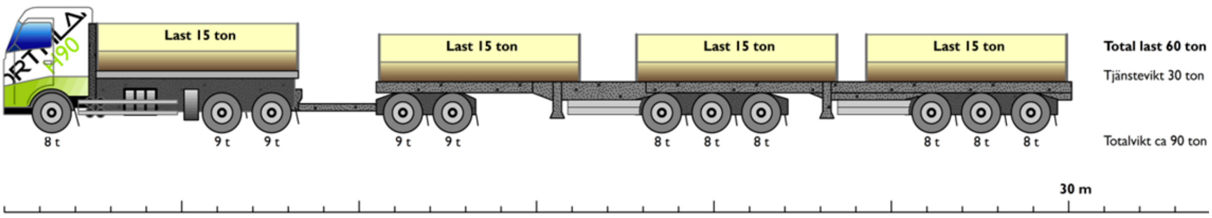
"Boliden" 72 ton truck

A combination with 9 axles, four on the truck and five on the trailer. The dimensioning (critical) load used for the calculations is 3 x 8 ton triple bogie. Total weight of the combination is 72 tons and net load 49 tons. Total length of the combination is 20 m.



"En trave till" (one stack more) 90 ton truck

A combination of truck, dolly, link and trailer with 11 axles. The dimensioning (critical) load used for the calculations is 3 x 8 ton triple bogie. Total weight of the combination is 90 tons and net load 60 tons. Total length of the combination is 30 m.



6.3 Structural Impact of Different Haulage Options

The impact on the road was calculated for each truck option. The calculations were made separately for both road sections 505 and 515. The structure thicknesses used were the thicknesses of the weakest risk class (class 4) of each section. The calculated structures are presented on table 10.

Table 10. The structures used in the calculations for the impact of heavier truck options.

Structure	Layer	Thickness [mm]	Modulus [MPa]
Road section 505, risk class 4	Bound	162	3000
	Base	129	200
	Unbound	482	100
	Subgrade		10
Road section 515, risk class 4	Bound	127	3000
	Base	403	200
	Unbound	590	100
	Subgrade		10

Special interest was focused on the displacement of weak subgrade (modulus 10 MPa) under different truck configurations. The other critical part of the structure is the pavement for which another assessment approach, based on the "fourth power rule" evaluation method, was employed. In addition, the performance of the pavement and the upper part of the base course were also evaluated based on the horizontal tensile strains at the bottom of the bound layers and the vertical compressive strains on the top of the unbound base course.

Subgrade displacement

At first, the subgrade displacement was calculated for the heaviest (the dimensioning) axle group of each truck option. For the standard 60 ton truck option 9,5+9 ton double bogie is the heaviest axle group. For the "Boliden" 72 ton truck and for the "En trave till" 90 ton truck the heaviest axle group is 3 * 8 ton triple bogie.

The comparison of the truck options on weak subgrade (modulus 10 MPa) based on the heaviest axle group of each option is presented in figure 36. The subgrade displacement induced is lowest for the standard 60 ton truck, but the 72 ton and 90 ton options are not much worse. The displacement in road section 515 is somewhat smaller than in section 505, which is due to thicker base course and overall structure in section 515.

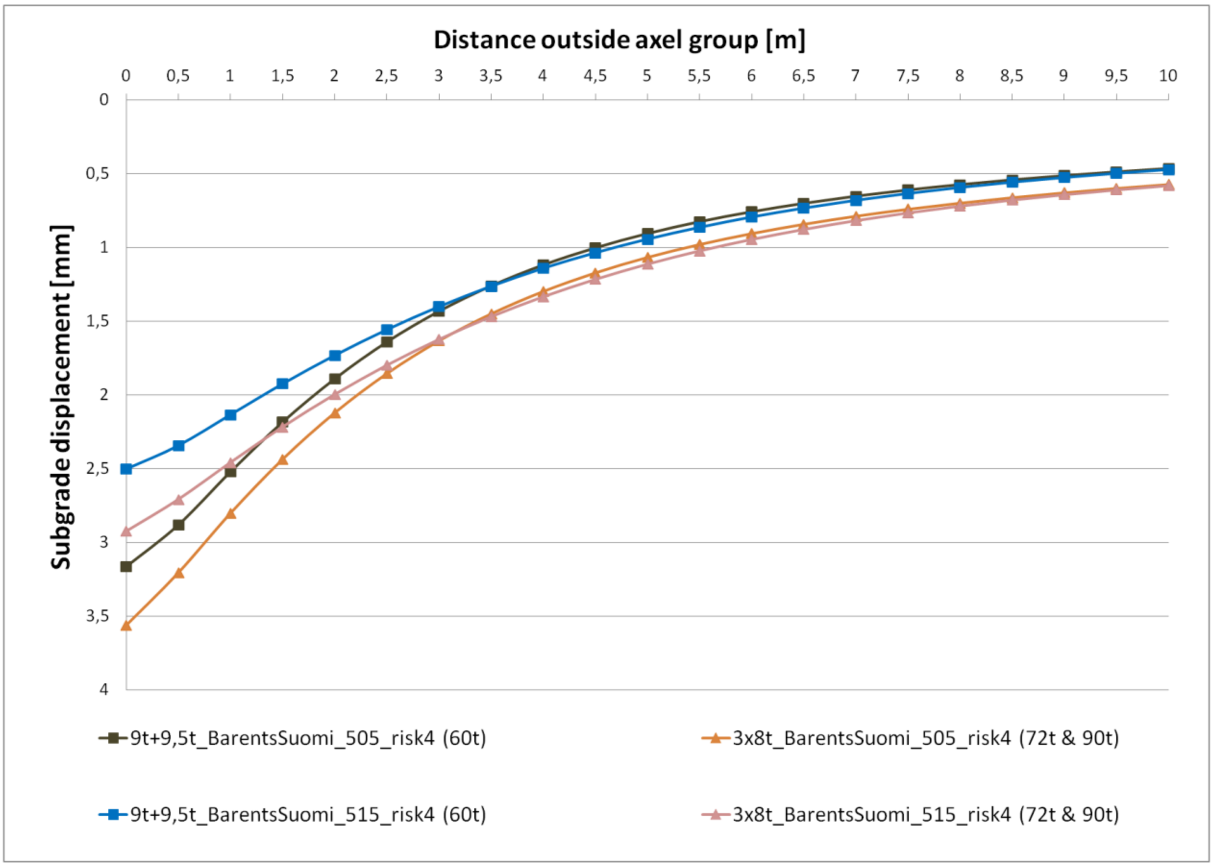


Figure 36. Comparison of the truck options on weak subgrade (modulus 10 MPa) based on the heaviest axle group of each option.

The next phase was to calculate the cumulative effect of the consecutive axles or axle groups on the truck combination. In other words, each axle or axle group of the truck combination increases the displacement if there is not sufficient time for the road structure to recover after it has been loaded. Figure 37 shows the cumulative displacement of weak subgrade (modulus 10 MPa) calculated for each truck option on both road sections. In this comparison 60 ton is again the best option. The 72 and 90 ton options are slightly worse, but approximately on the same displacement level with each other.

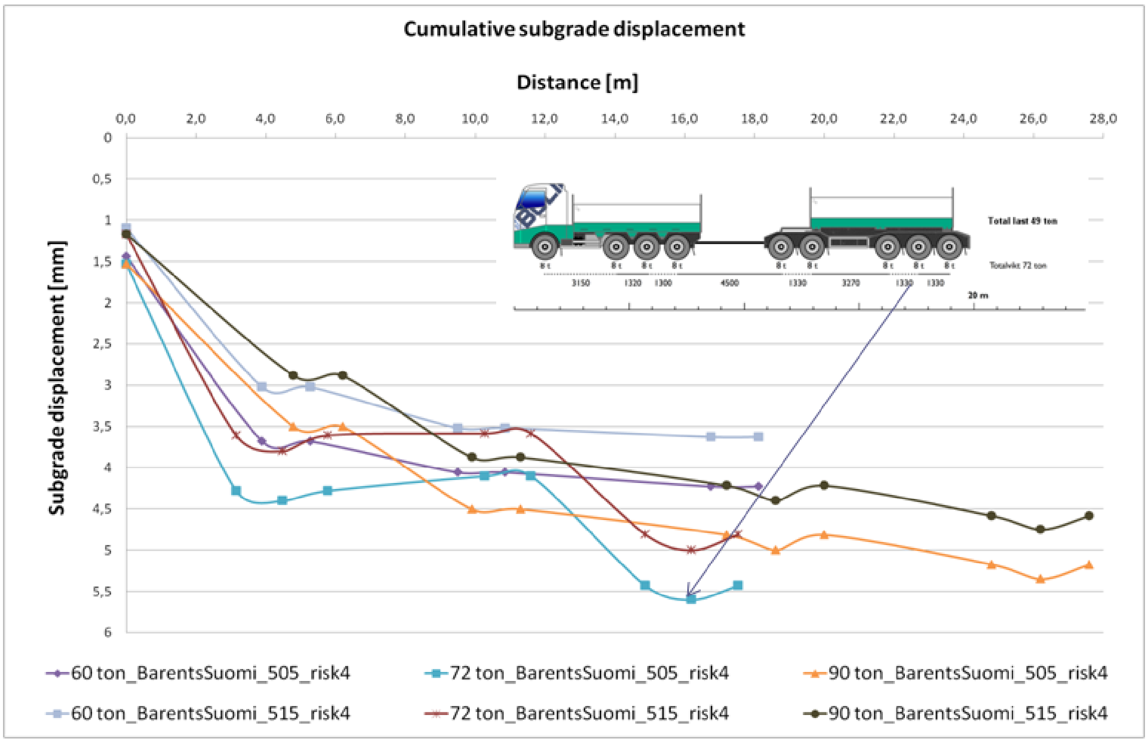


Figure 37. The cumulative displacement of weak subgrade (modulus 10 MPa) calculated for each truck option on both road sections. The horizontal axis presents the distance from the first axle of the truck. Zero is the first axle and the dots along the displacement curve represent the locations of the consecutive axles. On the vertical axis is the cumulative subgrade displacement calculated in one point.

Figure 37 shows that the cumulative subgrade displacement is about 30 - 40 % higher with 72 ton or 90 ton truck than with a standard 60 ton truck, the difference is at maximum about 2 mm. It should also be noted that the calculated cumulative subgrade displacement level represent an optimistic / conservative estimate. This is because it is known that the subgrade recovery in reality is not as immediate as the BISAR® calculation shows, for example due to development of excess pore water pressure. In real terms the cumulative effect could in unfavorable conditions be even stronger.

<u>Pavement</u>

Another challenge in comparing the different truck options is the effect of different trucks on pavement performance. That is because PMS objekt calculations were based on standard axle loads. That is why, in addition to displacement calculations with BISAR® software, another separate comparison of the truck options was also performed based on the classical "fourth power rule" used in pavement engineering. This rule slightly underestimates rutting and overestimates pavement distress but in general is still quite reliable in estimating pavement performance under different loadings.

The fourth power rule was defined as EKV = $(p/p_{ref})^4$. The equivalent loading value was calculated for each of the truck options based on the number of axles and the axle load. After that the estimated current annual transportation of 4,4 million tons (a theoretical maximum value based on assumption that all heavy traffic consists of fully loaded 60 ton trucks) was divided by the net weight of the truck in order to obtain the number of truck loads. Finally the load effect of each truck option was determined by multiplying the number of truck loads by the corresponding truck equivalent.

The results of the fourth power rule calculations are presented on table 11. The value in the last column is the factor of comparison to standard 60 ton truck and it shows that, based on this assessment, both heavier truck options are better compared to standard truck. The 72 ton truck is 27 % better and the 90 ton truck is 11,2 % better than the 60 ton option according to this calculation.

Table 11. The results of the fourth power rule calculations about the effect of different trucks to pavement performance.

Truck option & total weight	Axel loads					Truck EKV	Net weight	Truck loads	Load effect	Comparison to 60 ton
	7,5 ton	8 ton	8,5 ton	9 ton	9,5 ton		[ton]			
Standard 60 ton	1	2	0	3	1	3,918	38	116800	457671	1
"Boliden" 72 ton	0	9	0	0	0	3,686	49	90580	333913	0,730
"En trave till" 90 ton	0	7	0	4	0	5,492	60	73973	406232	0,888
Annual transportation (ton) = 365 days * 320 heavy vehicles (60 ton trucks)/day * 38 tons/vehicle =										4438400
Stress exponent used in calculations =			4							

The performance of the pavement and the upper part of the base course were also evaluated based on the horizontal tensile strains at the bottom of the bound layers and the vertical compressive strains on the top of the unbound base course. The results of these calculations are presented in table 12. The results show that the strains induced to the road structures by the heavier truck options are even lower than the strains induced by the standard 60 ton truck. Accordingly, on the basis of this evaluation, the heavier truck options are better options than the standard 60 ton truck. The strains on all cases are fairly low, well below critical limits, so there should not be immediate danger for pavement fatigue or mode 1 rutting.

Table 12. The results of the strain calculations at the bottom of the bound layers and on the top of the unbound base course. Positive values indicate tensile strains and negative values indicate compressive strains. The unit of the strain values is µstrain.

	Max. horizontal pavement strain		**Max. vertical strain on top of unbound structure**	
	60 ton	**72 & 90 ton**	**60 ton**	**72 & 90 ton**
Section 505, risk class 4	229,8	193,3	-501,2	-435,3
Section 515, risk class 4	249,4	219,1	-697,1	-611,0

On the basis of the impact analysis of different haulage options, it can be stated that the 72 ton and the 90 ton truck options are only slightly worse options than the standard 60 ton truck when the displacement of the subgrade is examined. When the performance of pavement and upper parts of the unbound structures are examined, the heavier truck options are found to be even somewhat better than the standard option. Therefore it can be concluded that the "normal" rehabilitation designed for the 60 ton truck is also enough for the 72 ton and 90 ton options.

6.4 Recovery times

If heavier truck options will be used recovery times after each truck pass will be a critical issue because if these times are too long there is a risk for increasing pore water pressure which leads to road failures. Recovery times were evaluated by the delay times of KUAB FWD measurements from time history data. This delay time can be considered as minimum recovery time but not the maximum. Figures 38 and 39 present results of data analysis and these figures show that at 50 kN load level the pavement structure response is linear elastic in all risk classes and that is why recovery times will not be a major risk issue when evaluating the heavy haulage impact to the road structure deformation risk.

However impact analysis results have shown that both test road sections have frost heave problems in certain places and higher rut depth can be located in these areas. That is why, if heavier haulage options will be used, convoy driving should be avoided especially on the spring thaw weakening time.

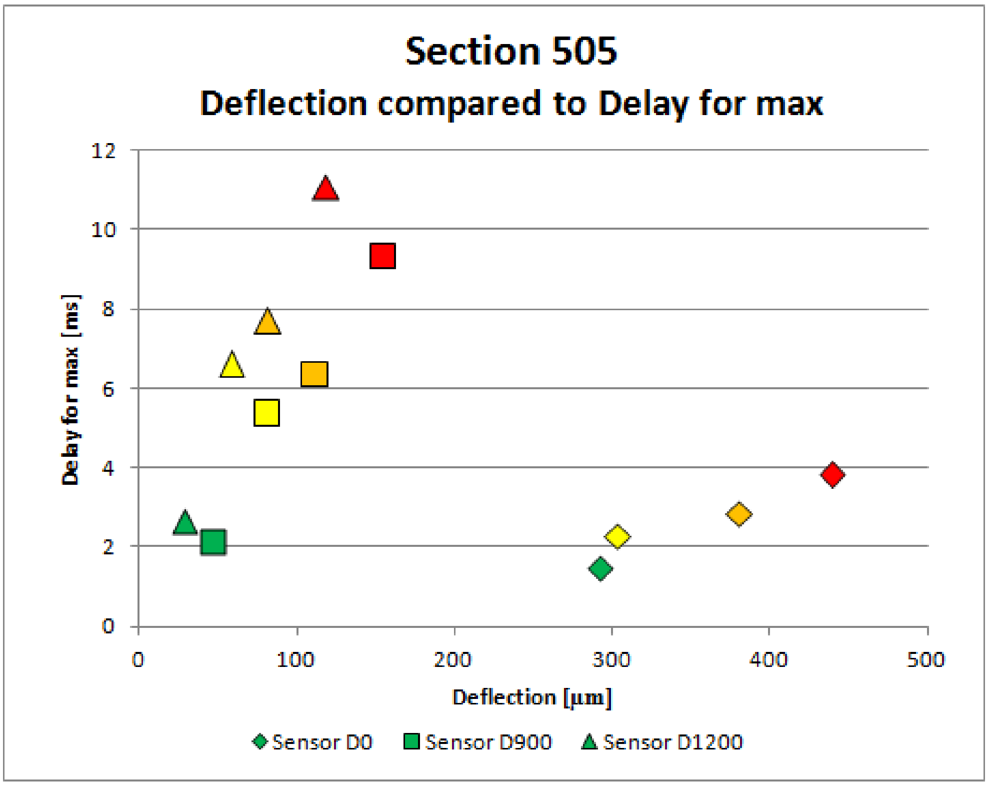


Figure 38. Maximum value of deflection compared to delay for max value on road section 505. Green dots present risk class 1, yellow dots risk class 2, orange dots risk class 3 and red dots risk class 4.

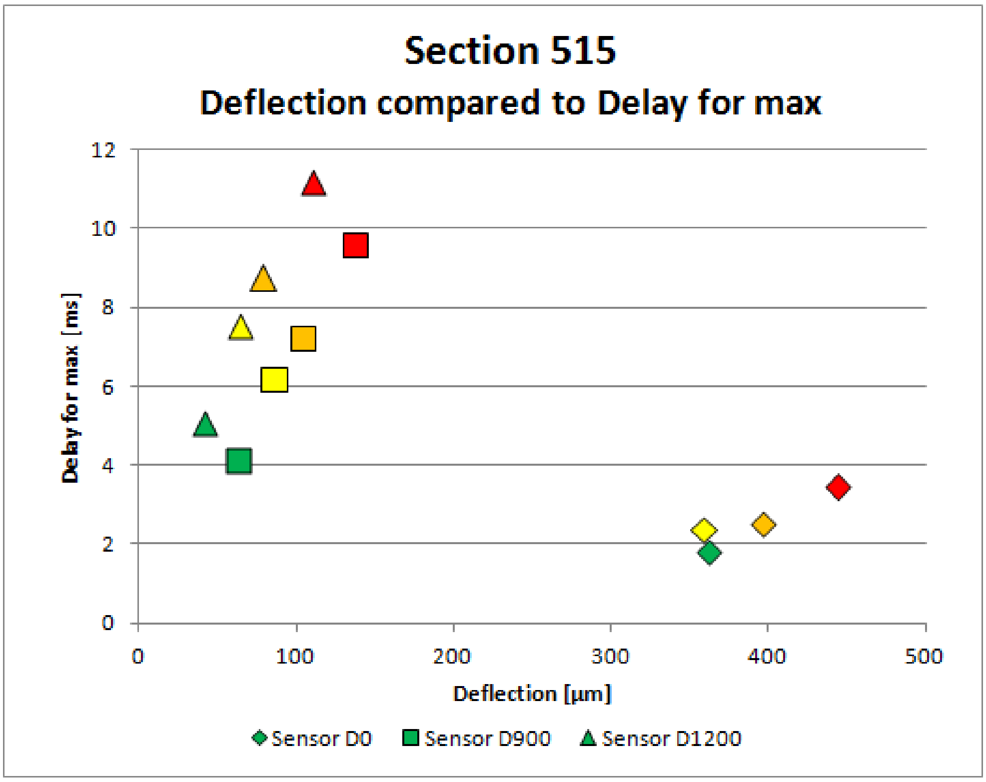


Figure 39. Maximum value of deflection compared to delay for max value in road section 515. Green dots present risk class 1, yellow dots risk class 2, orange dots risk class 3 and red dots risk class 4.

6.5 Cost evaluations

According to the principles, presented in previous chapters, the costs for required rehabilitation operations were estimated. The cost estimate calculation includes only the materials and work for road strengthening (pavement, bound base, unbound base). In section 515 the estimated prices do not include the section of the aircraft emergency landing strip.

With initial traffic the average costs are 14140 €/km in section 505 and 10103 €/km in section 515. If the heavy traffic increases by 50%, the average price/km will increase 10,7% in section 505 and 20,5% in section 515 in comparison to the initial traffic situation. If heavy traffic increases 100% the costs will be increase 19,4% (505) and 39,8% (515) and if heavy traffic increases by 200% the costs will be increase 77,4% (505) and 42,7% (515) compared to the initial traffic situation. The maximum costs are in road section 505 25090 €/km and 515 18456 €/km which can be stated as relatively low costs.

Table 13. The estimated prices for different options on both road sections.

	Initial traffic		**Heavy traffic +50%**	
Section	**Total price [€]**	**Average price/km [€]**	**Total price [€]**	**Average price/km [€]**
505	83582	14140	92560	15659
515	71802	10103	86551	12178

	Heavy traffic +100%		**Heavy traffic +200%**	
Section	**Total price [€]**	**Average price/km [€]**	**Total price [€]**	**Average price/km [€]**
505	99757	16877	148305	25090
515	100399	14127	131167	18456

7. Summary and Recommendations

Due to the increasing importance of transport economics and environmental issues, much greater attention will be given to haulage options heavier than the standard 60 ton trucks in Northern Europe. Highway 4, between Sodankylä and Rovaniemi, is one road with the potential to host a variety of industry projects in which the benefit would be higher loads. One project could focus on timber haulage from the Sodankylä/Ivalo area to Rovaniemi, while the transportation of wood chips for energy production to the new Rovaniemi power plant and transport of mining ore from new mines in the Sodankylä area to the railway in Rovaniemi are two other sectors for potential projects.

The impact of different heavy haulage options, 60 ton, 72 ton and 90 ton trucks, were calculated for two test sections utilizing current transportation tonnage values and then scenarios whereby the current tonnage would increase up to 200 %. In this work road sections 505 and 515 were first surveyed in detail to collect information concerning the current structural and functional condition of the road. The key testing techniques were laser scanner technique, ground penetrating radar technique and falling weight deflectometer technique as well as digital video. After that a risk analysis and structural analysis was made to calculate the impact of different haulage options on the performance and lifetime of the test road sections.

The results of structural analysis showed that pavement structures in both test sections are in relatively good shape and, thanks to relatively thick total structure depths, the displacements in the road structure / subgrade interface, even in the weakest sections, would be relatively low. The more critical issue is the poorly performing road drainage system which is causing differential frost heave problems and also permanent deformation and rutting during the spring thaw weakening period. That is why, if heavier haulage options are to be used, convoy driving should be avoided especially during the spring thaw weakening period. One interesting issue revealed during the drainage and frost heave analysis was that poor drainage in the immediate vicinity of many private road exits caused big problems on the main road.

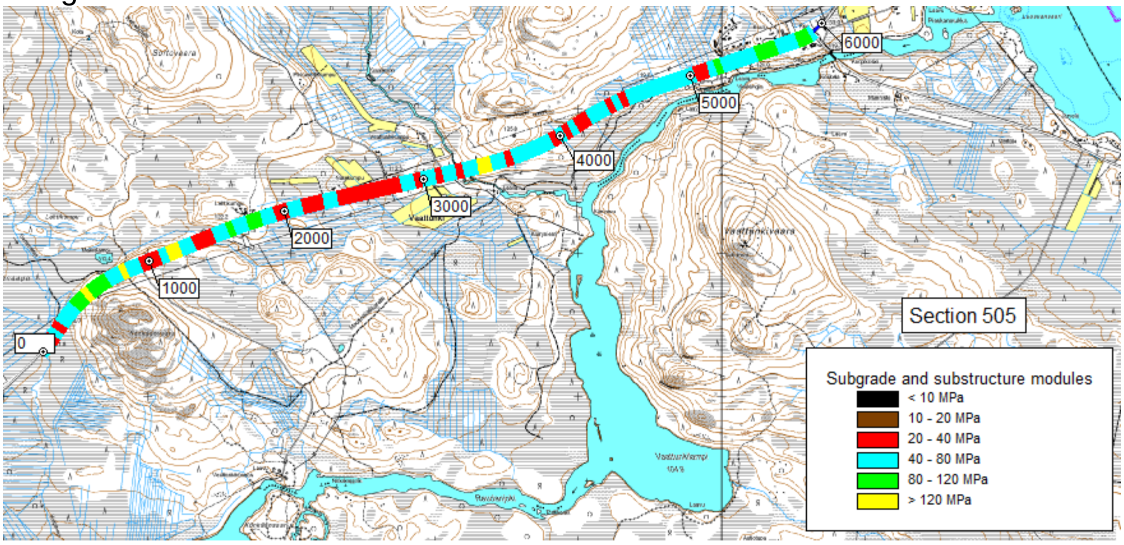
The impact analysis calculations for the heavier vehicle options, higher than the standard 60 ton truck, showed that displacement in the road structure / subgrade interface, caused by longer and heavier vehicles, is somewhat higher than displacement caused by standard trucks. On the other hand, heavier vehicles are somewhat friendlier to the top part of the pavement structures especially if the calculations are based on the haulage tonnage. Trucks equipped with CTI equipment do not provide an extra benefit especially with heavier truck options as the bound layer thickness is relatively high in both test sections and because these trucks are only using these main roads. In other roads the use of CTI is strongly recommended to avoid mode 1 rutting problems.

However, before drawing final conclusions about the benefits of heavier truck options, it should be kept in mind that this analysis focused only on the structural evaluation of road sections. In addition to road structures bridges especially have to be inspected and detailed calculations concerning the impact of heavy loads on the bridges should be made. A third important area that should still be investigated is the impact of heavier vehicles with respect to noise and vibrations in areas of human settlement.

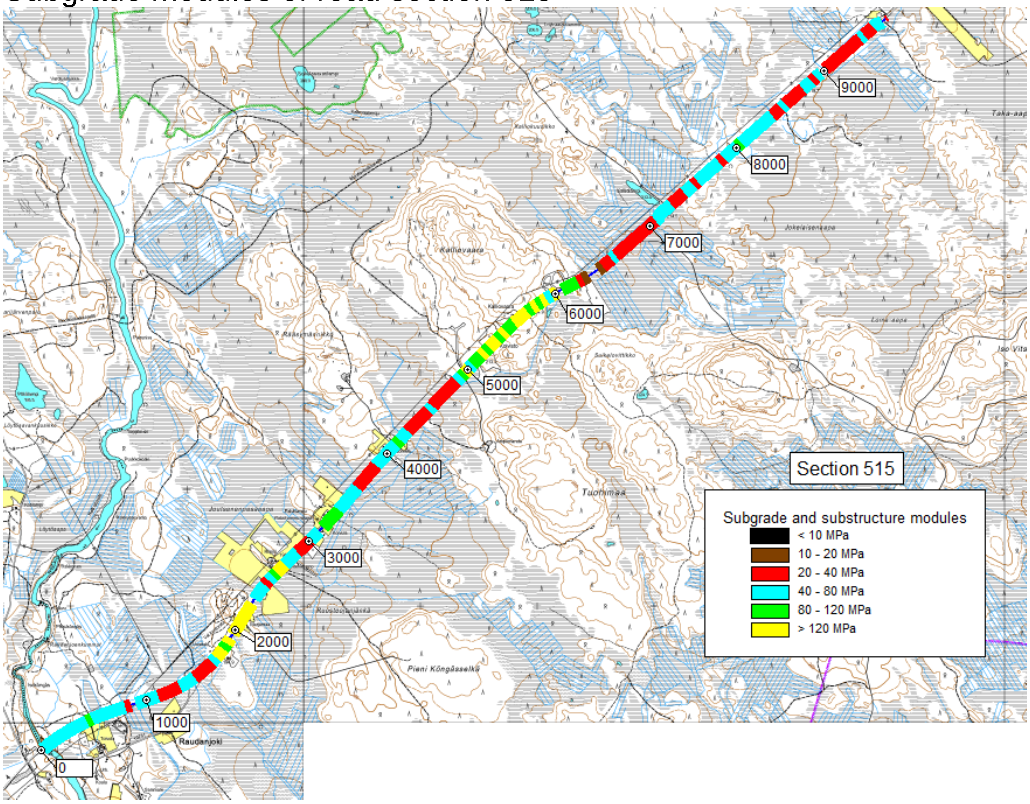
Appendixes

Appendix 1

Subgrade modules of road section 505

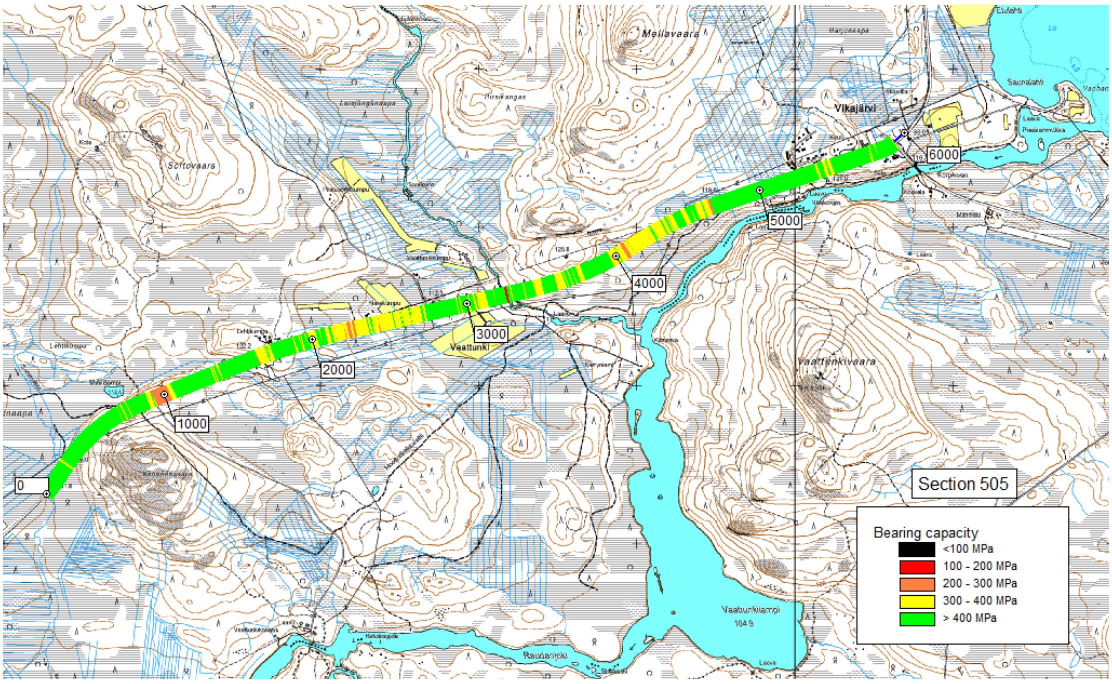


Subgrade modules of road section 515

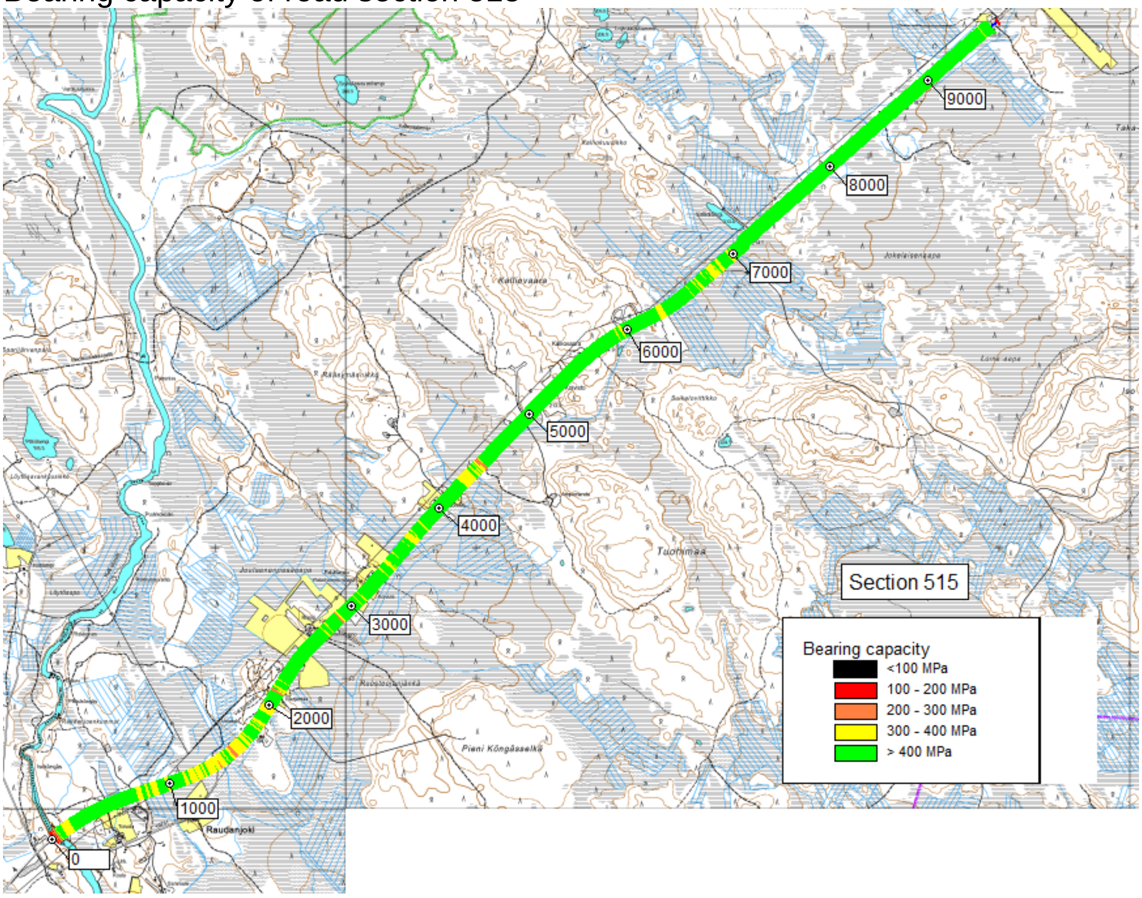


Appendix 2

Bearing capacity of road section 505

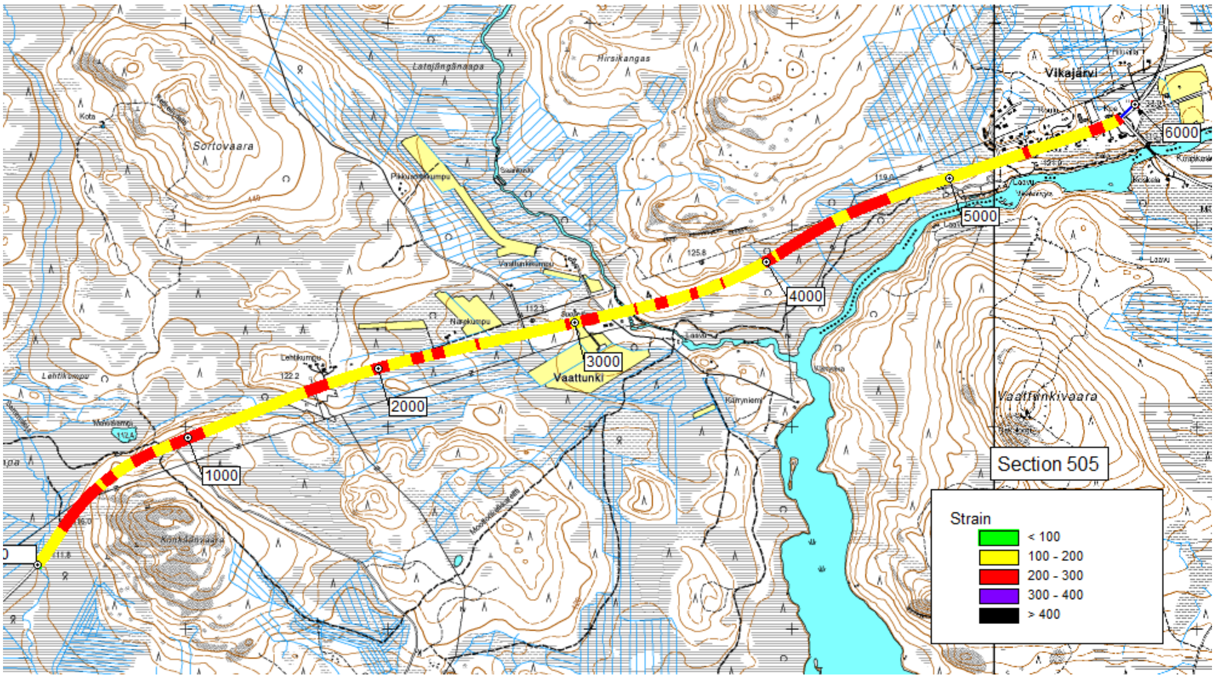


Bearing capacity of road section 515

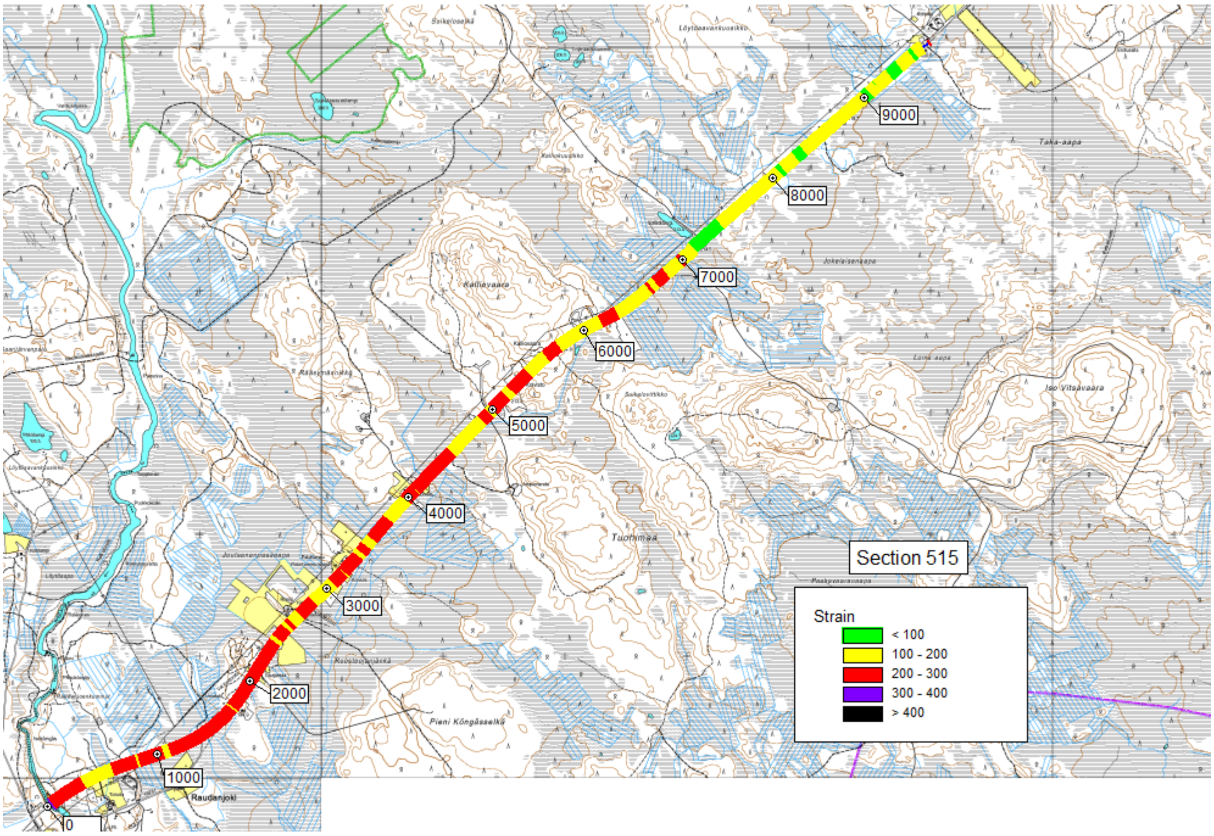


Appendix 3

Strain values of road section 505

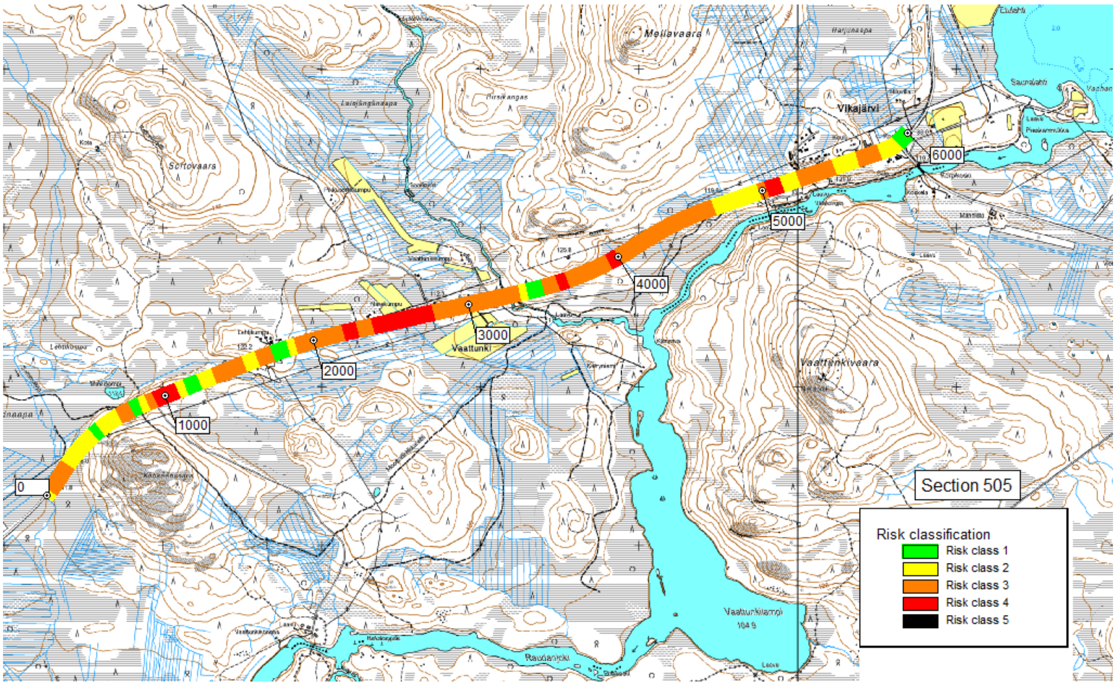


Strain values of road section 515



Appendix 4

Risk classification of road section 505



Risk classification of road section 515