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REHABILITATION OF THE FOREST ROAD TIMMERLEDEN
Design proposals

A ROADEX demonstration report

ABSTRACT

The European Union ROADEX Project 1998 – 2012 was a trans-national roads co-operation that aimed at developing ways for interactive and innovative management of low volume roads across the European Northern Periphery. Its main goals were to facilitate co-operation and research into the common problems of constructing and maintaining low volume roads in harsh climates.

This report gives a summary of a local demonstration of ROADEX methods for assessing forest roads for heavy timber traffic and based on the results making a rehabilitation design proposal.

Using the ROADEX-method the road was first surveyed using the modern non-destructive road survey techniques of video, ground penetrating radar and falling weight deflectometer. Three samples were also taken to check the gradings and to verify the GPR-results. Following this an integrated analysis was carried out using Road Doctor software to produce a strength assessment of the road. The results were then used to do an analytical design of the strengthening measures needed to carry the load from the timber trucks.

The ROADEX method was compared to regular road condition assessments and rehabilitation proposals from the project partners: The Swedish Forest Agency and the forest companies Sveaskog and SCA Forest. The partners used their normal procedures for field surveys, analyses and design. The comparison included:

- Design
- Volumes of road materials used,
- Environmental influence
- Costs for
    - Design
    - Materials
    - Construction works
    - Environmental impact

The results demonstrate that making a more careful road condition investigation and an analytical road rehabilitation design based on the road condition analyses, can reduce the overall rehabilitation costs.

KEYWORDS

ROADEX, forest roads, assessment, strengthening design, materials, environmental impact, costs.

PREFACE

This is a report from Task D3 of the ROADEX "Implementing Accessibility" project, a technical trans-national cooperation project between The Highland Council, Forestry Commission Scotland and the Western Isles Council from Scotland; the Northern Region of The Norwegian Public Roads Administration; the Northern Region of The Swedish Transport Administration and the Swedish Forest Agency; the Centre of Economic Development, Transport and the Environment of Finland; the Government of Greenland; the Icelandic Road Administration; and the National Roads Authority and the Department of Transport of Ireland.

The lead partner of the ROADEX "Implementing Accessibility" project was the Northern Region of the Swedish Transport Administration and the project consultant was Roadscanners Oy from Finland.

This report records a demonstration of the use of ROADEX methods to assess a forest road for heavy timber traffic and to make a rehabilitation design proposal. The works includes the initial survey, data interpretation, road condition analyses, assessment of rehabilitation needs and a rehabilitation design proposal. The report was prepared by Svante Johansson, Roadscanners Sweden AB and Per Christoffersson, Swedish Forest Agency. Tomi Herronen, Roadscanners OY did the analyses and the dimensioning work. Mika Pyhähuhta of Laboratorio Uleåborg designed the graphic layout and Ron Munro, Munroconsult Ltd, project manager of the ROADEX IV Project, checked the language.

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    - Martin Osbäck, Sveaskog
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ROADEX "Implementing Accessibility" Lead Partner: The Swedish Transport Administration, Northern Region, Box 809, S-971 25 Luleå. Project co-ordinator: Mr. Krister Palo.

CONTENTS

1. INTRODUCTION

1.1. THE ROADEX PROJECT

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

The Partners in the ROADEX “Implementing Accessibility” project comprised public road administrations and forestry organisations from across the European Northern Periphery. These were The Highland Council, Forestry Commission Scotland and the Western Isles Council from Scotland, The Northern Region of The Norwegian Public Roads Administration, The Northern Region of The Swedish Transport Administration and The Swedish Forest Agency, The Centre of Economic Development, Transport and the Environment of Finland, The Greenland Home Rule Government, The Icelandic Public Roads Administration and The National Roads Authority and The Department of Transportation of Ireland.

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

The project was awarded NPP funding in September 2009 and held its first steering Committee meeting in Luleå, November 2009.

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

Consultancy Service" and "Knowledge Centre". Three research tasks were also pursued as part of the project: D1 "Climate change and its consequences on the maintenance of low volume roads", D2 "Road Widening" and D3 "Vibration in vehicles and humans due to road condition".

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

1.2. ROADEX DEMONSTRATION PROJECTS

The aim of the ROADEX demonstration projects was to demonstrate the use of ROADEX strategies and technologies locally in the Partner areas to encourage their general use in the Partner offices. Projects were funded and executed by the local Partner offices with design and management support from the ROADEX consultancy service. The demonstration groups were:

D1 Drainage maintenance guidelines
D2 Road friendly vehicles and tyre pressure control
D3 Forest road policies and maintenance
D4 Rutting, from theory to practice
D5 Roads on Peat
D6 Health and vibration

All projects were delivered within the project timescale and reports are available on the ROADEX website at www.roadex.org.

1.3. TASK D3 FOREST ROADS POLICIES AND MAINTENANCE

The aim of the Task D3 projects, "Forest Roads Policies and Maintenance"" was to demonstrate the ROADEX methods of integrated survey and analysis for assessing of public and forest roads and, based on their results, making rehabilitation design proposals. These forms of integrated methods did not exist before being introduced in the ROADEX pilot project but since have gained increasing popularity in roads districts across the Northern Periphery.

1.4. THE SWEDISH DEMONSTRATION PROJECT

Forestry's need for forest roads with good bearing capacity continues to grow in importance. Good forest roads are necessary to enable the industry meet its year around demand for raw materials. The industry also faces changing climate patterns that will require new practices to be developed for road rehabilitation and construction. These will be subject to increasing environmental regulation on the use of finite natural resources, such as the manufacture of road materials that will directly influence costs. All these factors call for new rehabilitation design principles to ensure the durability of forest roads, and reduce the impact of material use.

The Swedish forest road demonstration project was a technical co-operation between The Swedish Forest Agency, Sveaskog, SCA Forest AB, The Swedish Road Authority and Roadscanners that was set up to identify optimum methods for rehabilitating existing forest roads.

The ROADEX project had developed new methods for the rehabilitation design of low volume roads including forest roads, including forest roads, based on careful field surveys of road condition. These methods were tested on the Timmerleden forest road and compared with standard road surveys and design proposals from the Partners. As part of the project Roadscanners prepared a rehabilitation design proposal based on the ROADEX methods and this was compared with rehabilitation proposals from Swedish Forest Agency, Sveaskog and SCA Forest AB. The comparison included design, volumes of road materials used, environmental influence and costs.

2. PROJECT TARGET

The overall aim of the project was to develop a design method for rehabilitating forest roads that optimizes the resources used for a given bearing capacity and quality.

The target of the demonstration was to compare the currently available design technologies for environmental impact, costs and quality. The results will be used to prepare recommendations for future rehabilitation plans mainly for forest roads.

3. THE TIMBER ROAD

3.1 GENERAL

“Timmerleden” is a forest road situated about 50 km west of the city Boden in the north of Sweden (see Figure 1). The length of the rehabilitation section is approximately 5 km and the finished road will have a width of 4.5 m. The section has an average daily traffic of about 25 heavy vehicles and a few personal cars. The road is open to traffic around the year.

The road was previously rehabilitated in 2005 and the bearing capacity of the road improved. The rehabilitation included approximately 700 tons/km of 0-70 mm sub-base material, 500 tons/km of roadbase material and 350 tons/km of wearing course. As a result of the rehabilitation the road was able to carry heavy vehicles throughout the year, apart from a few weak sections that caused problems during the spring thaw each year.

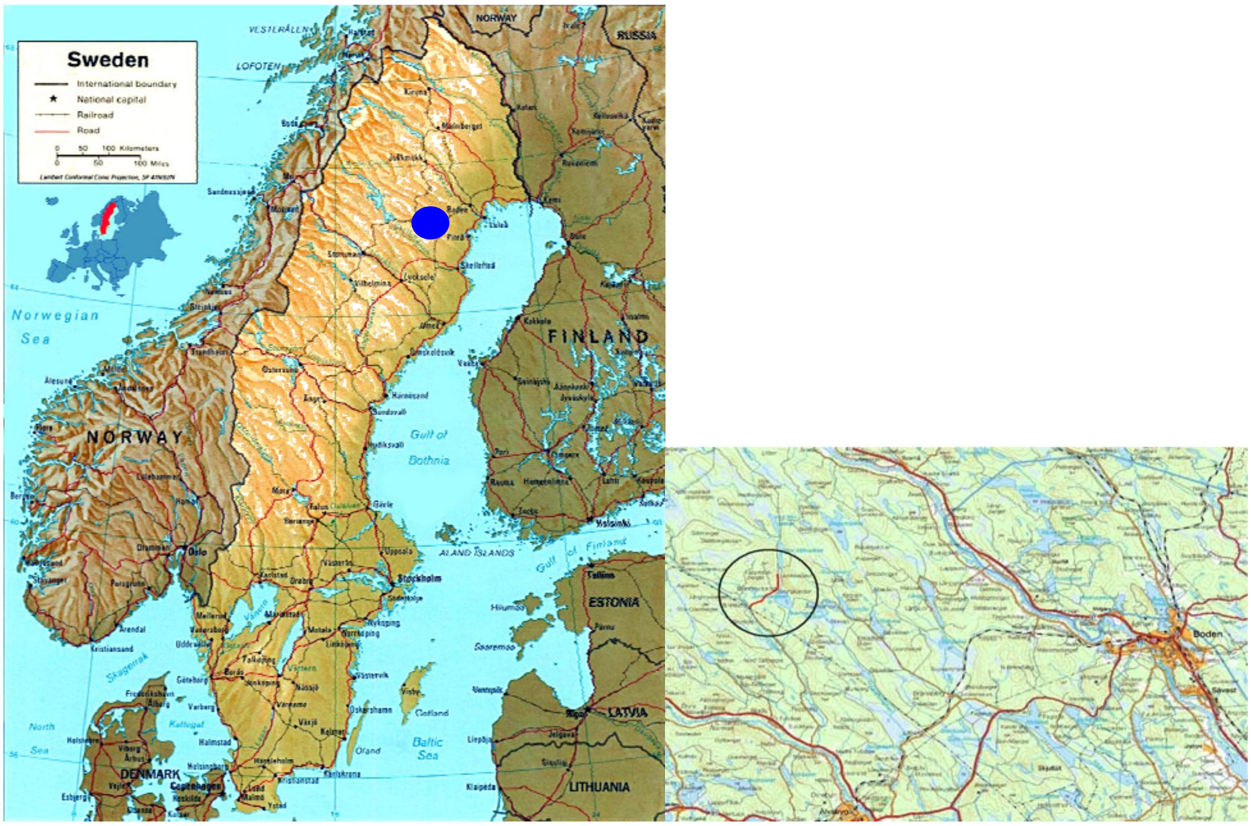

Figure 1 Map of Sweden with the demonstration project position marked as a blue point and as a black circle on the local map.

3.2 THE ROAD CONDITION

Some sections of the road were weak and had caused problems previously in the springtime. The road normally had 1-2 weeks of load restrictions during the spring thaw. As can be seen from Figure 2 the road also had some surface defects during the summer and the ditches were not in good shape. The map in Figure 3 shows the road close to water bodies in many places and Figure 4 shows that standing water can be close to the road surface in many places.

Figure 2 Road condition in July 2010.

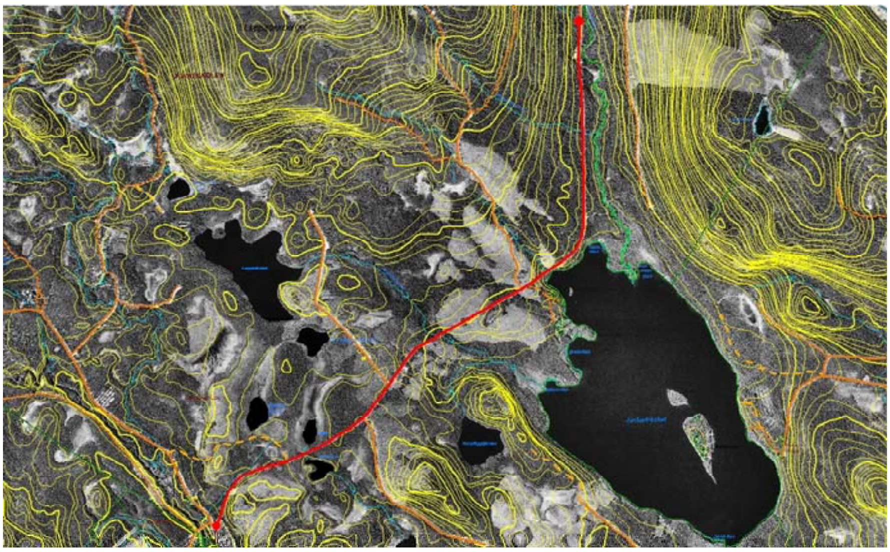

Figure 3 Map showing the Timmerleden Road close to water.

Figure 4 Water in the ditch close to the road surface.

4. THE REHABILITATION DESIGN

4.1 INTRODUCTION

Each of the partners in the Swedish demonstration project were asked to prepare their own rehabilitation proposal for the Timmerleden Road. It was emphasized that the structural design would be the main part of the project. The Roadscanners proposal was prepared in accordance with the methods developed in the ROADEX project and the other partners made their proposals in accordance with their normal procedures. The proposals for each partner are described individually below.

4.2 DESIGN BY SWEDISH FOREST AGENCY

4.2.1 Road survey method

The designer walks along the road and records the recommended rehabilitation measures section by section. The equipment used is a distance measurement wheel, folding rule, camera and sometimes a spit and a spade for sampling. The designer also checks the performance of all culverts along the road during the survey.

4.2.2 Design proposal

The design proposal of the Swedish Forest Agency requires a road base layer of 100 or 250 mm depending on the condition of the road and the estimated traffic loading. An unbound wearing course of 70 mm of gravel is then laid on top of the strengthened base layer as shown in Figure 5. The proposal also recommended the rehabilitation or replacement of 14 crossing culverts.

Dimensioning proposals for Timber Road, length 5 km, width 4,5 m; layer thickness in millimeters
Swedish Forest Agency

Road sections	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	100	100	250	250	250	100	100	100	100	100	100	100	250	250	250	250
Sub-base																				
Ditch left																				
Ditch right																				

Road sections	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900	1950	2000
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	250	250	250	100	100	100	100	100	100	100	100	100	100	100	100	250
Sub-base																				
Ditch left																				
Ditch right																				

Road sections	2050	2100	2150	2200	2250	2300	2350	2400	2450	2500	2550	2600	2650	2700	2750	2800	2850	2900	2950	3000
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	250	250	100	100	100	100	100	100	100	100	100	100	250	250	250	250	250	250	100	100
Sub-base																				
Ditch left																				
Ditch right																				

Road sections	3050	3100	3150	3200	3250	3300	3350	3400	3450	3500	3550	3600	3650	3700	3750	3800	3850	3900	3950	4000
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	100	250	250	100	100	100	250	250	100	100	100	100	100	100	100	100
Sub-base																				
Ditch left																				
Ditch right																				

Road sections	4050	4100	4150	4200	4250	4300	4350	4400	4450	4500	4550	4600	4650	4700	4750	4800	4850	4900	4950	5000
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Sub-base																				
Ditch left																				
Ditch right																				

Figure 5 Design proposal from Swedish Forest Agency.

4.3 DESIGN BY SCA FOREST AB

4.3.1 Road survey method

The designer travels along the road in a car equipped with distance measurement equipment and records the recommended rehabilitation measures section by section.

4.3.2 Design proposal

The design proposal from SCA Forest AB contains a base course layer of 100 or 200 mm depending on the road condition and the estimated need for rehabilitation to withstand the traffic load. On top of the base course an unbound wearing course of 70 mm of gravel is proposed as shown in Figure 6. On three shorter sections SCA Forest AB proposes ditch cleaning to improve drainage. Cleaning of bushes is proposed for the whole length of the section.

Dimensioning proposals for Timber Road, length 5 km, width 4,5 m; layer thickness in millimeters
SCA Forest AB

Road sections	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	200	200	200	200
Sub-base																				
Ditch left																				
Ditch right																				

Road sections	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900	1950	2000
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Sub-base																				
Ditch left																				
Ditch right																				

Road sections	2050	2100	2150	2200	2250	2300	2350	2400	2450	2500	2550	2600	2650	2700	2750	2800	2850	2900	2950	3000
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	200	200	100	100	100	100	100	100	100	100	100	200	200	100	100	100	100
Sub-base																				
Ditch left																				
Ditch right																				

Road sections	3050	3100	3150	3200	3250	3300	3350	3400	3450	3500	3550	3600	3650	3700	3750	3800	3850	3900	3950	4000
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	100	100	100	200	200	200	200	200	200	200	200	200	200	200	200	200
Sub-base																				
Ditch left													■						■	
Ditch right																				

Road sections	4050	4100	4150	4200	4250	4300	4350	4400	4450	4500	4550	4600	4650	4700	4750	4800	4850	4900	4950	5000
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	200	200	200	200	200	200	200	100	100	100	100	100	100	100	100	100	200	200	200	200
Sub-base																				
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Ditch right																				

Figure 6 Design proposal from SCA Forest AB.

4.4 DESIGN BY SVEASKOG

4.4.1 Road survey method

The designer travels along the road in a car equipped with distance measurement equipment and records the recommended rehabilitation measures section by section.

4.4.2 Design proposal

The design proposal from Sveaskog is a standard rehabilitation measure of 150 mm sub-base and 60 mm of road base throughout the road. An unbound wearing course of 60 mm of gravel is then laid on top of the road base layer as shown in Figure 7.

Dimensioning proposals for Timber Road, length 5 km, width 4,5 m; layer thickness in millimeters
Sveaskog

Road sections	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				

Road sections	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900	1950	2000
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				

Road sections	2050	2100	2150	2200	2250	2300	2350	2400	2450	2500	2550	2600	2650	2700	2750	2800	2850	2900	2950	3000
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				

Road sections	3050	3100	3150	3200	3250	3300	3350	3400	3450	3500	3550	3600	3650	3700	3750	3800	3850	3900	3950	4000
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				

Road sections	4050	4100	4150	4200	4250	4300	4350	4400	4450	4500	4550	4600	4650	4700	4750	4800	4850	4900	4950	5000
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				

Figure 7 Design proposal from Sveaskog.

4.5 DESIGN BY ROADSCANNERS

4.5.1 Design procedure

The ROADEX design procedure has 6 steps:

- Step 1 - data collection
- Step 2 - project setup; processing and interpretation
- Step 3 - moduli calculations for road structure and subgrade soil
- Step 4 - initial bearing capacity
- Step 5 - new design; target bearing capacity
- Step 6 - checking the design with additional data.

The six stages of the procedure are described below.

4.5.2 Step 1 - Data collection

Roadscanners carried out the following surveys as a basis for the design of the rehabilitation measures:

- Survey with ground penetration radar (GPR)
- Field survey with video and GPS observing
    - Road damages
    - Culverts
    - Ditches
- Bearing capacity measurements with falling weight deflectometer
- Sampling (thickness and grading)

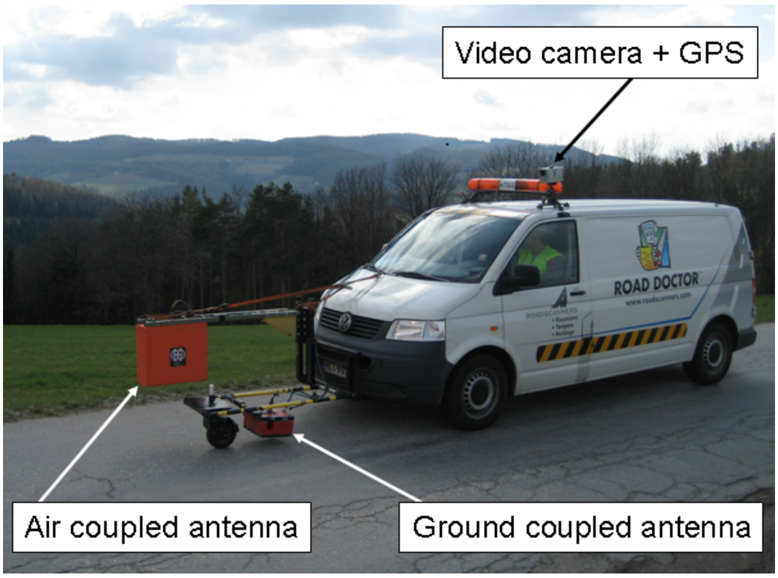


Figure 8 Survey van with GPR antennas, GPS and video.

The GPR survey was carried out by Roadscanners OY with two antennas; one ground coupled 400 MHz antenna for details deep down in the road structure and one air coupled 1 GHz antenna for the details in the upper part of the road structure (Figure 8). The aim of the survey was to find the layer thicknesses in the road structure and the total thickness of the road structure.

A video of the road was taken during the survey and notes made of the road condition and ditch classification using Cam Link software. Oral comments were also recorded on the road condition by means of a microphone (Figure 9). Detailed information on the culvert condition was given by Per Christoffersson, Swedish Forest Agency, who walked the road and took photos of the culverts. Positioning was by GPS.

A Falling Weight Deflectometer survey was carried out by DMC Projektering AB with a KUAB FWD (Figure 10) in accordance with The Swedish Transportation Agency's method VVMB 112. The testing interval was 40 measurement points/km.

The falling weight deflectometer aims to simulate the passage of a wheel load of a 5 ton wheel load over a road surface (I e half of a 10 ton's axle). As the FWD weight hits the ground the deflection of the road surface is measured in the load centre and at various distances from the centre. By using the data obtained it is possible to analyse the risk of deformation in the upper or lower layers in the road. It is also possible to use the layer information from the GPR measurement and the deflection results from the FWD measurements to estimate the layer modulus in the different structural layers at every FWD measurement point. The measurement principle is shown in Figure 11.

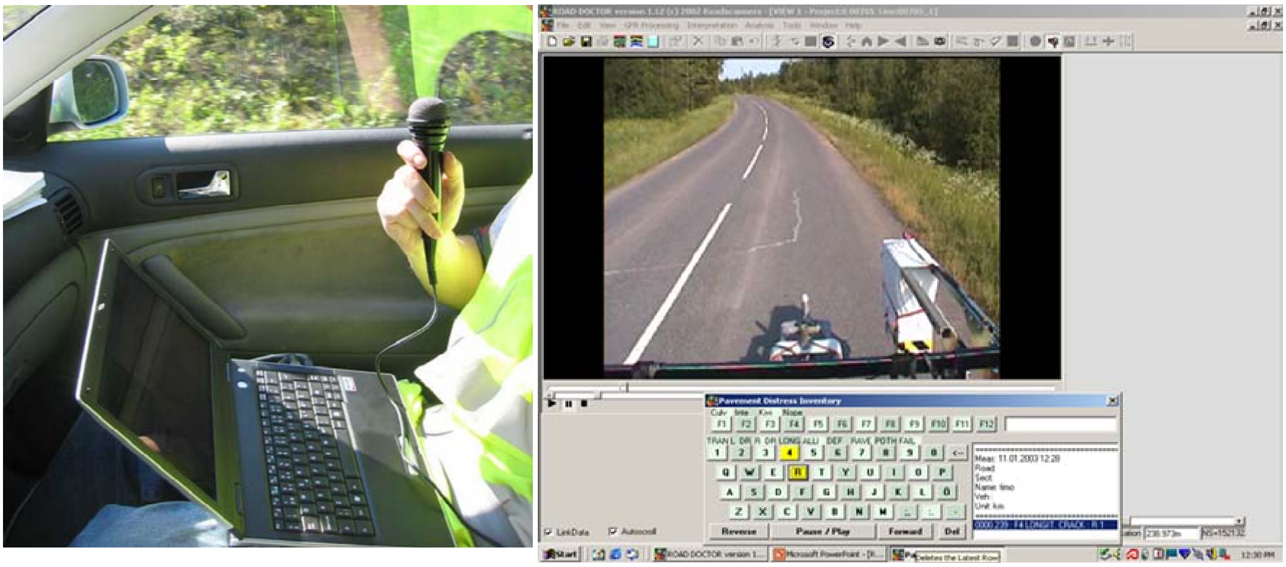


Figure 9 Recording road data during the road survey

Figure 10 Falling Weight equipment used on the Timmerleden Road

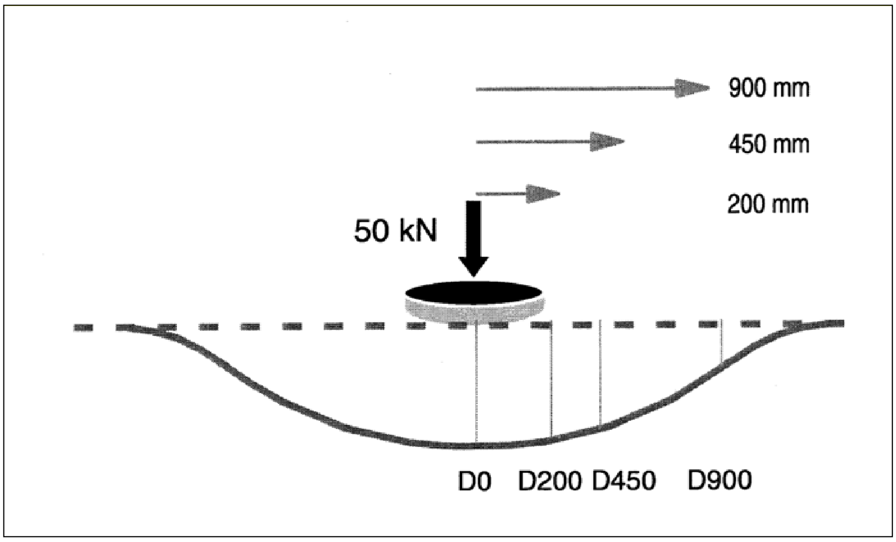


Figure 11 Deflections measured under the Falling Weight Deflectometer

Samples were taken from the road structure in three places by DMC Projektering AB to verify the GPR-results and to check material quality. The sampling points were selected from the GPR data during the preliminary check. The samples were taken using a small excavator. The thicknesses of the different road layers were measured and the samples sent to a laboratory for analyses of the material grading. The thicknesses in the three sampling places are shown in Table 1 and the grading for the sub-base is shown in Figure 12. The grading for the sub-base is rather dense with a fines content of about 15 %, indicating that the material might be water sensitive.

Table 1 Road layer thickness at the sampling points.

Section	Layer type	Accumulated thickness, cm
1/020	Wearing course and base course Sub-base Subgrade	0-5 5-57 57- moraine
3/650	Wearing course and base course Sub-base Sub-base Subgrade	0-5 5-27 sand + crushed gravel 27-40 stony fine sand 40- silty moraine
4/290	Sub-base Sub-base Sub-base	0-23 crushed gravel 23-45 stony sand 45- stony silty sand

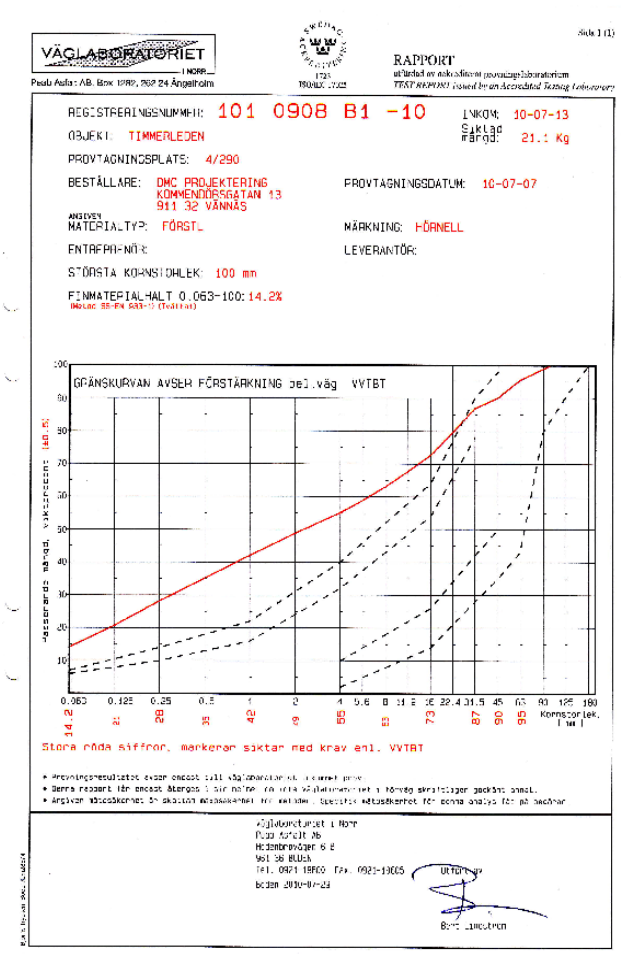


Figure 12 Grading for sub-base

4.5.3 Step 2 - Project setup; processing and interpretation

The project can be setup based on GPS length if there is no other information available. The survey lengths can be scaled if needed.

The GPR interpretation of the wearing course was interpreted from the high frequency antenna. This interpretation can be difficult sometimes if there are old structures present or if the wearing course has not been laid. If that is the case it has to be left out of the back calculations. The overall structure thicknesses were interpreted from the lower frequency antenna. It is also possible to interpret the embankment thickness where needed. The locations of the culverts were marked on the GPR data (this can be obtained from a culvert inventory if available).

Based on the FWD and GPR data an estimate of the subgrade type can be given. The minimum for this estimate is to mark possible peat and bedrock sections.

All of the survey data was then gathered together in Road Doctor software as show in Figure 13. In the top window, the blue line indicates the thickness of the wearing course. The next window shows the thickness of the wearing course and the thickness of the structure with red lines. The next window shows the same thing but with the GPR radargram removed. The fourth window shows the moisture content in the upper layer. The fifth window shows the deflection bowls from the FWD measurement and the sixth window shows an analysis from the FWD measurements and at the bottom photographs show the condition of the culverts. All of the data is shown in its position along the road.

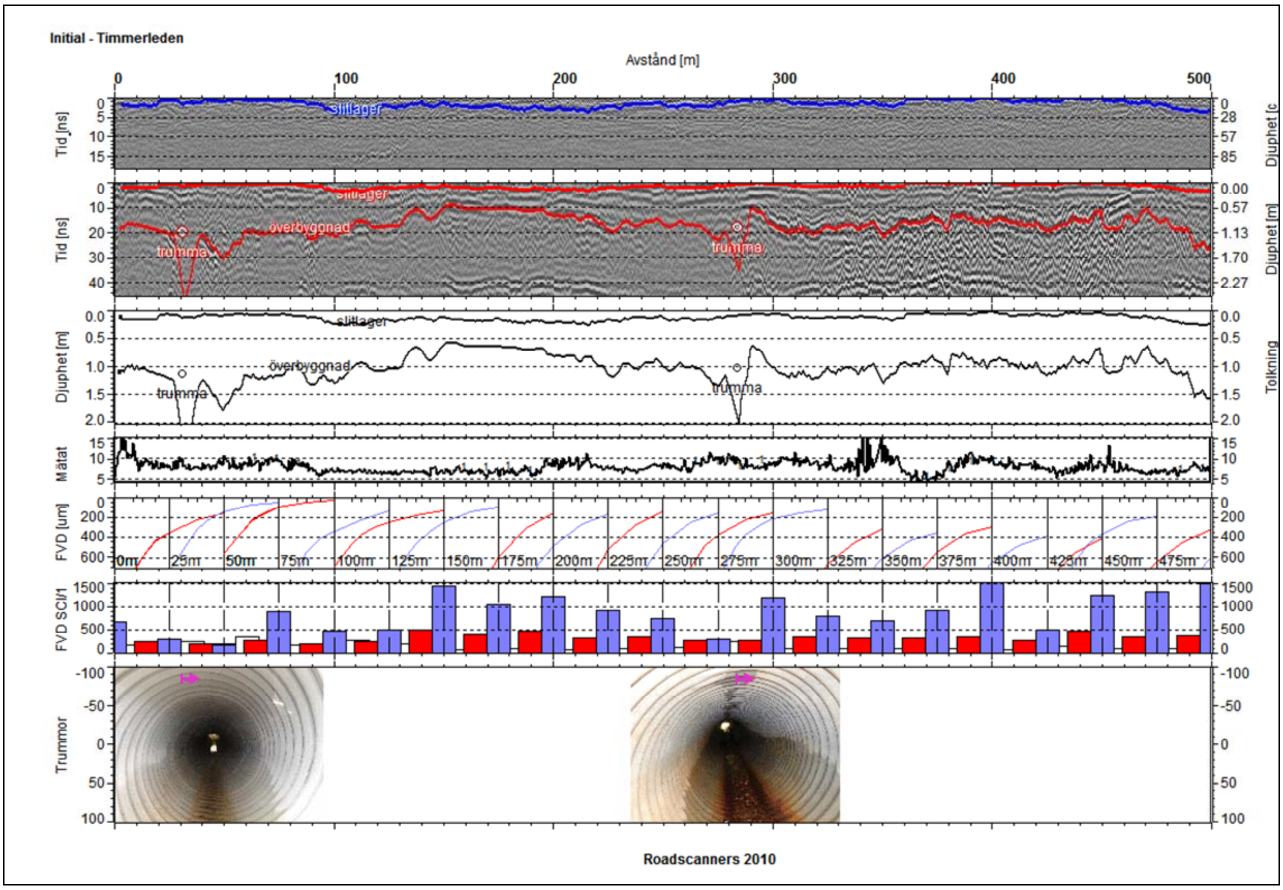


Figure 13 Assembled view of the road condition for section 0-500 m of Timmerleden.

The video from the road can be viewed on the computer screen linked to all data.

4.5.4 Step 3 - Moduli calculations for road structure and subgrade soil

The bearing capacity analysis suite in the Road Doctor software can be used to calculate Swedish bearing capacity indexes and classes, as well as subgrade moduli (E_u). Once the GPR interpretations has been carried out the layer moduli can be calculated using the Road Doctor forward calculation tool, based on algorithms published by the US Department of Transport Federal Highway Administration (FHWA). The calculation can also be carried out using the Elmod back calculation software tool made by Dynatest. Other back calculation software packages can also be used but are not integrated into Road Doctor software.

Once the moduli values were calculated the results were transferred back into the Road Doctor Odemark dimensioning analysis tool analysis bar. In most cases a combination of back calculated and forward calculated structural layer moduli values combined with Swedish bearing capacity calculation results for subgrade moduli values will give the best results.

Following the transfer of the layer moduli, the initial sectioning was reviewed. During this process the calculated initial 100 m sections were shortened or lengthened according to GPR data and video information. This meant defining exactly, for instance, where the peat subgrade started and ended. An example of the results is shown in Figure 14.

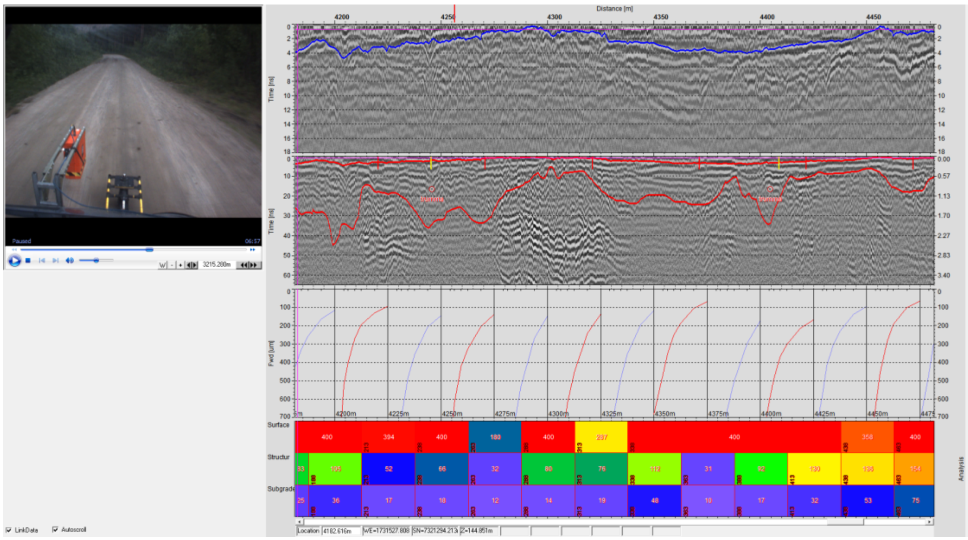


Figure 14 Moduli of the structure layers. 1 GHz antenna data on top, second 400 MHz antenna data, third FWD deflection curve and below the calculated moduli values of surface, structure and subgrade layers.

4.5.5 Step 4 - Initial bearing capacity

The initial bearing capacity was calculated using the Odemark tool. A short description follows:

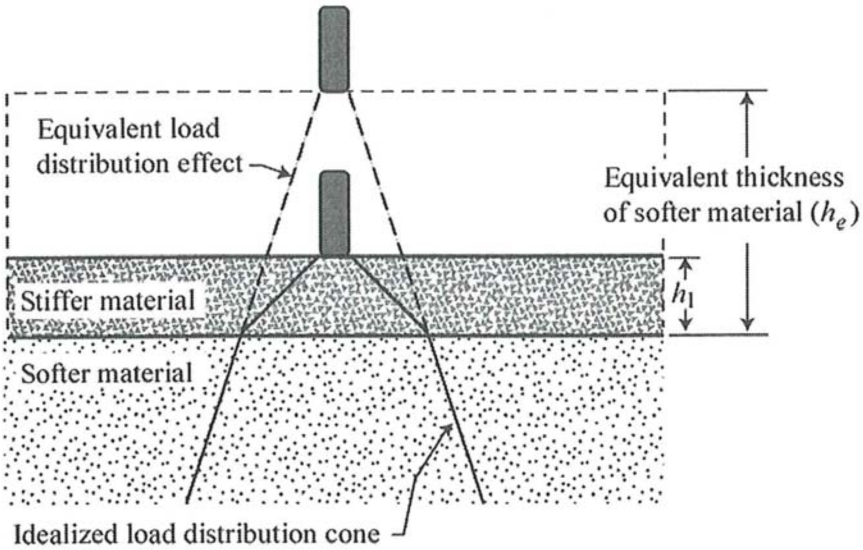


Figure 15 The general principle of the Odemark dimensioning method.

The increase in bearing capacity on the top of a structural layer, compared to the bearing capacity below the layer, is determined by both the layer thickness and modulus. Thus the bearing capacity on the top of the pavement structure is determined by the properties of the subgrade and each of the individual layers above the subgrade. The Odemark formula is a simple method for determining the bearing capacity of a layered structure. It does not take loading into account. The bearing capacity is calculated only on the basis of the thickness and the modulus of the layer. Nevertheless, the formula provides an easy way to evaluate if the structure is sufficiently stiff for the intended loadings on the road. The Odemark formula is well known and still very widely used in many countries for the structural design of roads. The formula is defined as follows:

$$E_P = \frac{E_A}{\left(1 - \frac{1}{\sqrt{1+0{,}81\times\left(\frac{h}{0{,}15}\right)^2}}\right)\frac{E_A}{E} + \frac{1}{\sqrt{1+0.81\times\left(\frac{h}{0{,}15}\right)^2\left(\frac{E}{E_A}\right)^{2/3}}}}$$

where

E_P = bearing capacity on the top of the layer being dimensioned [MPa]
E_A = bearing capacity beneath the layer being dimensioned [MPa]
E = the material elastic modulus of the layer being dimensioned [MPa]
h = thickness of the layer being dimensioned [m]

When calculating the initial Odemark bearing capacity the moduli values are used together with GPR thicknesses to create a continuous bearing capacity profile. This profile clearly indicates the weak sections over the road length as can be seen in Figure 16.

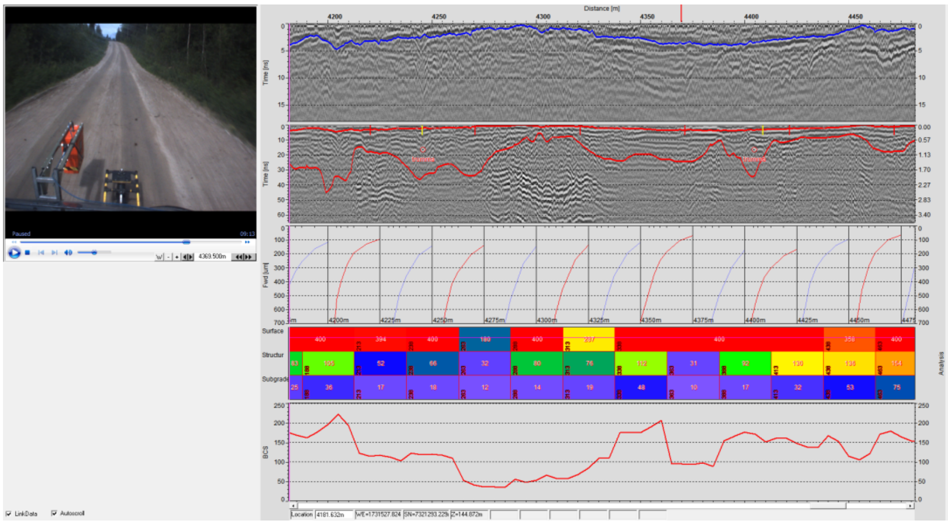
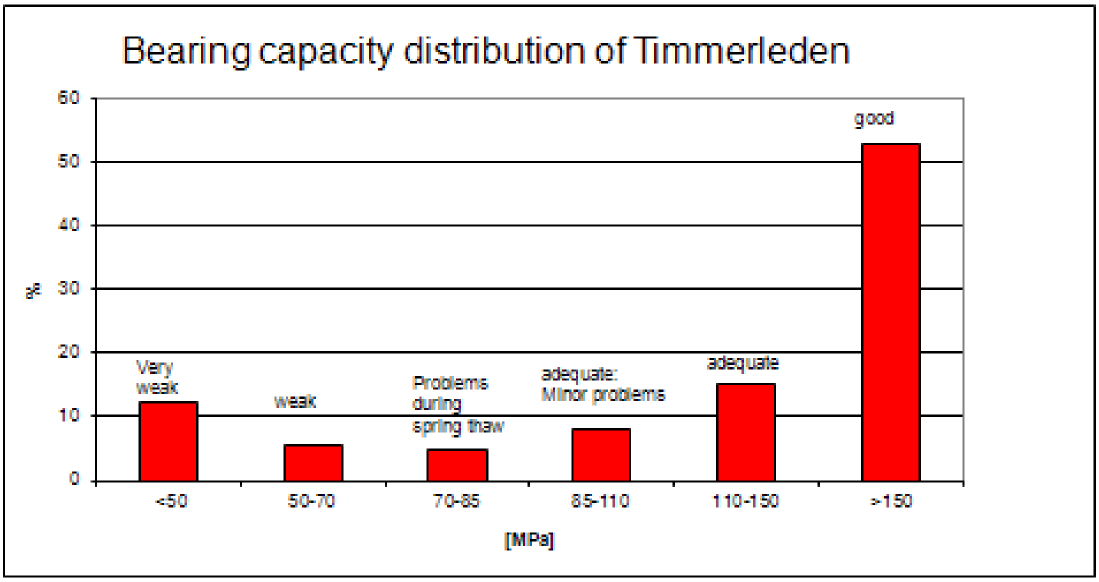


Figure 16. The principle of Odemark's dimensioning. The calculated initial bearing capacity is shown as a red line in the bottom window.

The distribution of the bearing capacity of a section of the Timmerleden road calculated according to the Odemark method is shown in Figure 17. This demonstrates that more than 75 % of the road had adequate or good bearing capacity according to Odemark.



Figur 17 The distribution of the Odemark bearing capacity for Timmerleden

4.5.6 Step 5 - New design; target bearing capacity

Using the built-in Odemark dimensioning tool and the planning tool in the Road Doctor software, different designs can be tested to identify the most beneficial design for each section of road. It is also possible to give a target bearing capacity to make it easier to compare the results. All parameters (names, road width, moduli values, etc.) in the planning tool are open for modifications.

A target bearing capacity of 90 MPa was chosen for the Timmerleden road. This was considered to be suitable for the road type and traffic situation. By using the Odemark dimensioning tool the rehabilitation measures for the Timmerleden road were then calculated using the Odemark tool to meet the target bearing capacity. The results from one road section are shown in Figure 18.

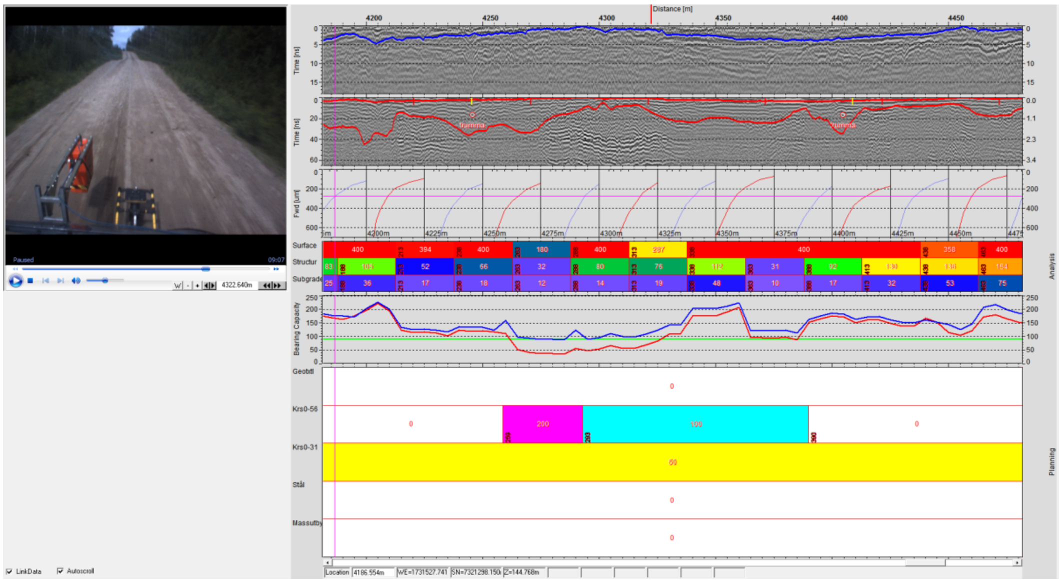


Figure 18. New design using Road Doctor software. The new bearing capacity has been calculated. The blue line in the Bearing Capacity sub-window shows the calculated effect of the designed structure. The green line is the target bearing capacity (90 MPa).

4.5.7 Step 6 – Checking the design with additional data.

The Odemark bearing capacity analysis has two weaknesses in forest road design that design engineers should keep in mind. The first one is that if bedrock is close to the surface the high subgrade moduli will give a high initial bearing capacity value – resulting in a strengthening structure that could be too weak, especially if there are Mode 1 rutting problems on the road. Mode 1 rutting occurs high up in the structure, close to the road surface. In such cases it is useful to check the “strain” value (E_a). This describes the strain at the bottom of the pavement, but it can also be used as a tool to estimate the risk of Mode 1 rutting on gravel surfaced roads. The higher the E_a-value is, the higher the risk of Mode 1 rutting. When high values appear, thicker structure layers should be considered even if the target bearing capacity has already been reached.

The other situation that design engineers need to be aware of, is where the road is constructed over a peat subgrade. Using the target bearing capacity value here may sometimes result in structures are too strong and cause a possible risk of settlements due to excessive weight. In such case a special lower design target moduli should be considered.

The video analysis (together with the map) can give important information on junctions and meeting places to avoid conflicts at raised elevations of the road profile. Video also helps to estimate the need for drainage improvements and any need for improving visibility along the road (bushes etc.).

The GPS coordinates can be used as a rough tool to show the geometry of the road. The GPS elevation along the survey line can be a useful support in making decisions.

The horn antenna bouncing (or elevation) data can be useful in estimating the roughness of the surface.

The “Integrated analysis” stage brings all the data being used together to get the best and most cost effective design for the road section. It means that the parts of the road that need light design – or no new structures at all – can be designed light enough and that the really weak sections of road can get strengthening that is strong enough. The complete design for a section of the Timmerleden road, and the additional data for checking the design, is shown in Figure 19.

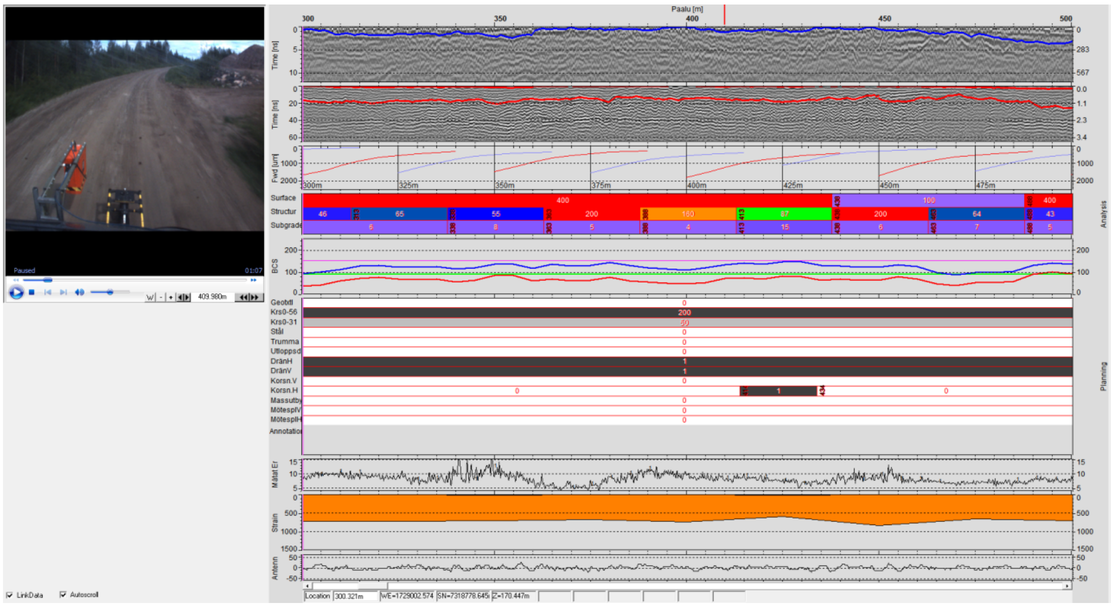


Figure 19. A Road Doctor screen with multiple subwindows for joint analysis and design. From the top: 1.0 GHz GPR antenna data; 400 MHz antenna data; FWD deflection curves; moduli values for three layers; calculated bearing capacities (red-initial, blue-designed, green-target); plan with inventories (junctions, meeting places); measured dielectric value of the surface; strain value; antenna bouncing.

Figure 20 shows the bearing capacity for the Timmerleden road before and after the proposed rehabilitation design calculated using the Odemark method. The figure shows that no weak spots will be left behind after the rehabilitation.

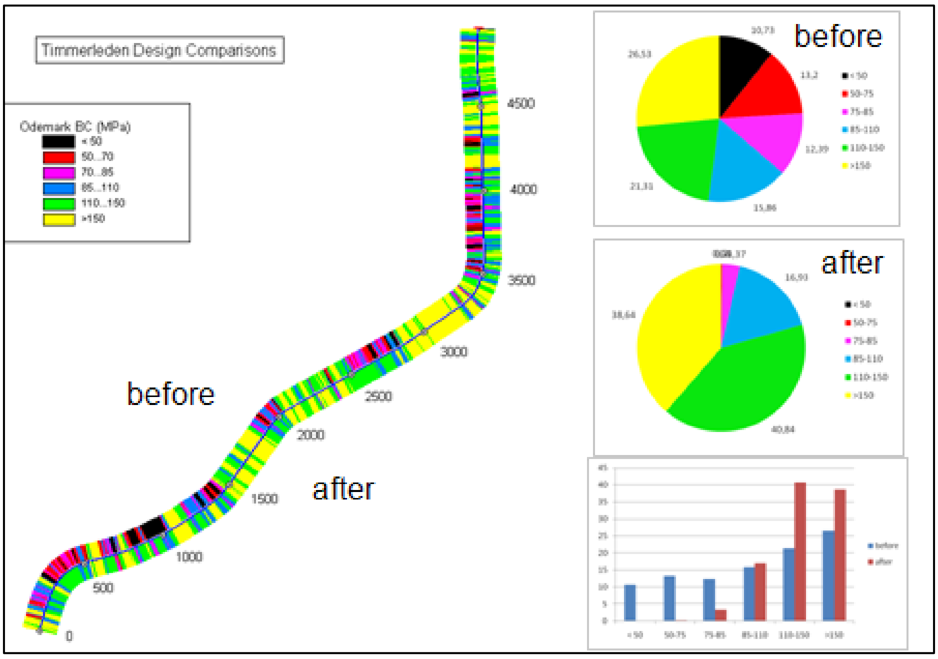


Figure 20 Odemark bearing capacity for Timmerleden before and after strengthening

4.5.8 Design proposal

The design proposal from Roadscanners is based on the results of the initial road survey together with the improvements to bring it up to the target bearing capacity. By using the

Odemark dimensioning tool the proposal is “tailor made” to the existing road so that the weaker spots will have thicker rehabilitation measures and any spots with good bearing capacity will only have a new wearing course. It is proposed that one weak section over peat is reinforced with a steel net and that the roadside ditches for the full length of the road are cleaned out. A section of the Roadscanners design proposal is shown in Figure 21.

Dimensioning proposals for Timber Road, length 5 km, width 4,5 m; layer thickness in millimeters
Roadscanners

Road sections	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
Wearing course	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base	100	100	100	100	100	100	200	200	200	200	200	100	100	100	200	250	250	250	250	250
Sub-base																				
Steel reinforcement																				
Ditch left																				
Ditch right																				
Road sections	**1050**	**1100**	**1150**	**1200**	**1250**	**1300**	**1350**	**1400**	**1450**	**1500**	**1550**	**1600**	**1650**	**1700**	**1750**	**1800**	**1850**	**1900**	**1950**	**2000**
Wearing course	150	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base	250				200	200	200	200	200	100								100	100	100
Sub-base																				
Steel reinforcement						10	10													
Ditch left																				
Ditch right																				
Road sections	**2050**	**2100**	**2150**	**2200**	**2250**	**2300**	**2350**	**2400**	**2450**	**2500**	**2550**	**2600**	**2650**	**2700**	**2750**	**2800**	**2850**	**2900**	**2950**	**3000**
Wearing course	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base	100							100			100	100	100	200	200	200	200			
Sub-base																				
Steel reinforcement																				
Ditch left																				
Ditch right																				
Road sections	**3050**	**3100**	**3150**	**3200**	**3250**	**3300**	**3350**	**3400**	**3450**	**3500**	**3550**	**3600**	**3650**	**3700**	**3750**	**3800**	**3850**	**3900**	**3950**	**4000**
Wearing course	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base						100				100	100	200	100	200	100	200	200	200	100	100
Sub-base																				
Steel reinforcement																				
Ditch left																				
Ditch right																				
Road sections	**4050**	**4100**	**4150**	**4200**	**4250**	**4300**	**4350**	**4400**	**4450**	**4500**	**4550**	**4600**	**4650**	**4700**	**4750**	**4800**	**4850**	**4900**	**4950**	**5000**
Wearing course	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base	100	100	100			200	100	100				200	200							
Sub-base																				
Steel reinforcement																				
Ditch left																				
Ditch right																				

Figure 21 Design proposal from Roadscanners.

5 COMPARISON OF DESIGN PROPOSALS

5.1 GENERAL

The design proposals from the four partners in the project have been compared and the amount of materials used has been calculated. An example of the comparison for the first kilometre of the road is shown in Figure 22. The complete comparison of the full road is given in Annex 1.

From this it can be seen that there are a number of similarities between Roadscanners’ proposal and that of Swedish Forest Agency. The thick rehabilitation measures are almost the same in places. There are also similarities between Roadscanners and SCA for thick rehabilitation measures. The Sveaskog proposal differs from Roadscanners as it has the same measures for the full length of the road. One basic difference between the Roadscanners proposal and the other partners is that Roadscanners only proposes a wearing course of 50 mm in many places as the road is calculated to be strong enough at these points.

Roadscanners also suggest the ditches should be cleaned out over the whole length of the road to improve the drainage. As the main concern of the project was structural dimensioning the roadside ditches have not been a main focus. It has however been proved in the ROADEX project, and has to be emphasized, that drainage is a very important factor to address as water is often the main reason for accelerated deterioration of roads.

Dimensioning proposals for Timber road, length 5 km, width 4,5 m; layer thickness in millimeters																				
	Road sections																			
COMPANY	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
Swedish Forest Agency																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	100	100	250	250	250	100	100	100	100	100	100	100	250	250	250	250
Sub-base																				
Ditch left																				
Ditch right																				
SCA Forest AB																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	200	200	200	200
Sub-base																				
Ditch left																				
Ditch right																				
Sveaskog																				
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				
Roadscanners																				
Wearing course	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base	100	100	100	100	100	100	200	200	200	200	200	100	100	100	200	250	250	250	250	250
Sub-base																				
Ditch left																				
Ditch right																				

Figure 22 Comparison of design proposals, section 0/000-1/000.

5.2 VOLUMES OF ROAD MATERIALS

The volumes of road materials for all proposals have been calculated in cubic metres of compacted layer thickness. The width of the road used in the calculations for all layers is 5,0 m including the edge strips. The results of the comparison are shown in Table 2.

Table 2 Comparison of volumes

Company	Wearing course	Road base	Sub-base	Sum aggregate	Ditching
	M3	M3	M3	M3	M
Swedish Forest Agency	1750	3363	0	5113	0
SCA Forest AB	1750	3338	0	5088	60
Sveaskog	1500	1500	3750	6750	0
Roadscanners	1250	2276	0	3526	10000

From this it can be seen that the Roadscanners proposal consumes the least amount of road material. It is due to the fact that by using the methods developed within the ROADEX project, rehabilitation measures can be designed directly on the basis of the detailed road condition surveys and data analyses. This means that the rehabilitation measures can be designed exactly at the right spots and to the right strength to achieve an overall bearing capacity that matches the chosen target for the project.

5.3 ENVIRONMENTAL ASPECTS

Environmental considerations have been a major concern in the road sector for a long time. Partners try to minimize their use of finite natural resources and the emission of carbon dioxide in their operations to low levels. The overall aim for the emission of carbon dioxide, CO_2, within European Union is to reduce the level with 20% by 2020 at the latest. The Swedish Forest companies have their own aims for CO_2-emission as follows:

- SCA: -20% CO_2 by 2020 at the latest
- Sveaskog: -30% by 2015 at the latest
- Skogsstyrelsen: The same as the EU aim and also to participate in discussions on sustainable development in society planning and to optimise the management of natural resources.

The CO_2-emission from the crushing process for various aggregates has been estimated based on figures from an aggregate supplier. The total figures for the use of road materials for each proposal have been calculated as follows:

- Skogsstyrelsen, 5113 m^3, => 28, 480 kg CO_2
- SCA Skog AB, 5088 m^3 => 29, 360 kg CO_2
- Sveaskog AB, 6750 m^3 => 37, 600 kg CO_2
- Roadscanners, 3526 m^3 => 19, 640 kg CO_2.

5.4 COSTS

5.4.1 General

The costs for the different proposals have been estimated and summarised in Table 3. The different cost items are presented in the following clauses.

5.4.2 Road materials and road work

The road material costs have been estimated for each proposal. For the purposes of the calculation it has been assumed that aggregates in all of the layers have the same unit cost. It has also been assumed that the aggregate cost is 10 €/m^3 when compacted on the road. This figure is considered to be a reasonable assessment of the current costs for the Partners and sufficient for the comparison of the proposals.

The Roadscanners proposal includes a reinforced section with steel nets. This has been used in the ROADEX project for rehabilitation of roads over peat and has worked very well. The cost for the reinforcement has been added at the normal cost level in Sweden.

The costs for grading the road are difficult to estimate and have been assumed to be equal for all proposals. A question mark has been placed in the table for this line.

It has similarly been assumed that the ditches should be cleaned out to improve the road quality and to prolong service life. Ditching is a cheap engineering measure and it has been proved in the ROADEX project that if resources are very limited ditching is the most profitable measure to do. In the cost table ditching costs have therefore been marked with a question mark, but it must be emphasized that all proposals will require to have good drainage to assure a good service life length.

5.4.3 Field survey, analyses and design

The ROADEX field surveys, analyses and design carried out by Roadscanners, were more extensive compared to the methods used by the Swedish Forest Agency and the forest companies. For the Timmerleden road the cost for this work was 8,500 €. The Timmerleden road was however a small demonstration project and the surveys were executed with more care than would normally needed on a standard rehabilitation project. The cost figures for the Partners are very low and have been estimated by the Swedish Forest Agency.

5.4.4 Environmental costs.

According to the Swedish Road Authority the costs for CO_2-emission can be set at 1,50 SEK/kg or 0.15 €/kg. Using these figures the costs for the emission of CO_2 for the different proposals have been calculated as follows:

- Skogsstyrelsen, 28,480 kg * 0,15 = 4 272 €
- SCA Skog AB, 29,360 kg * 0,15 = 4 404 €
- Sveaskog AB, 37,600 kg * 0,15 = 5 640 €
- Roadscanners, 19,640 kg * 0,15 = 2 946 €

5.4.5 Rehabilitation lifetimes

The ROADEX strengthening design, as proposed by Roadscanners, can be regarded as the optimal design. It is based on sound knowledge of the structural properties of the Timmerleden forest road and calculated using well-known methods with a reasonable target strain level. If this can be assumed to be correct the Partner proposals can be expected to deteriorate on those sections where their proposals have a thinner strengthening measure than Roadscanners'. For the purpose of the report all of the proposals have been assumed to have equal life lengths, but it should be kept in mind that some weak sections may be under dimensioned in the Partners' proposals and require additional strengthening in time.

5.4.6 Total costs.

The total costs for the four proposals are shown in Table 3. The costs for the Roadscanners' proposal are the lowest, even though the road condition survey and the design were more expensive compared with the partners' costs. The Swedish Forest Agency's and SCA Forest's proposals are approximately 14-15 % more expensive than Roadscanners proposal, and Sveaskog's proposal is just above 50 % more expensive.

Table 3 Comparison of costs

Company	Skogsstyrelsen	SCA	Sveaskog	Roadscanners
Aggregate complete on the road 10 €/M3	51 130	50 880	67 500	35 260
Steel net reinforcement 4 €/M2	-	-	-	1 840
Grading?	?	?	?	?
Ditching?	?	?	?	?
Field survey, analyses & design	500	250	250	8 500
Environmental costs, 0,15 €/kg	4 272	4 404	5 640	2 946
Total costs	55 902	55 534	73 390	48 546
Costs, €/M forest road	11,18	11,06	14,63	9,71
	115 %	114 %	151 %	100%

5.5 TECHNICAL ASPECTS

The use of objective measured data as a basis for the dimensioning, and the use of a recognised analytical design method, gives a number of advantages:

- Comparisons can be made with other projects, and decisions on rehabilitation measures
- Previously years of experience are not needed in order to carry out the rehabilitation design
- Basic measured data can be used to check the finished rehabilitation

6 CONCLUSIONS

A demonstration project of the ROADEX method for rehabilitation design of a forest road was carried out of Roadscanners on the Timmerleden forest road in Sweden. Detailed surveys of the road were conducted to assess the road condition and the information obtained used in an analytical design to calculate the structural need for the road to be brought to a target bearing capacity. The Roadscanners rehabilitation proposal was compared to normal rehabilitation proposals made by the Swedish Forest Agency, SCA Forest and Sveaskog. It was found that, in spite of much higher costs for road survey and design, the ROADEX method used by Roadscanners was 14 to 51 % cheaper than the Partners' proposals. The method was also found to save natural resources and reduce the emission of carbon dioxide. It was considered that the method could produce even better savings in larger road rehabilitation projects, or in the case of several smaller projects in the same area, where the unit costs of field surveys and design could be substantially decreased. In these circumstances it was considered that the possibilities of saving natural resources and money, and reducing the emission of carbon dioxide would be even better.

Analytical design based on surveyed road condition data can also provide other advantages:

- Decisions on design thicknesses can be objectively based on measured data
- Previous years of experience in the method is not required
- The finished rehabilitation can be checked objectively

ANNEX 1. COMPARISON OF REHABILITATION PROPOSALS

SECTION 0/000-1/000 M

Dimensioning proposals for Timber road, length 5 km, width 4,5 m; layer thickness in millimeters																				
	Road sections																			
COMPANY	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
Swedish Forest Agency																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	100	100	250	250	250	100	100	100	100	100	100	100	250	250	250	250
Sub-base																				
Ditch left																				
Ditch right																				
SCA Forest AB																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	200	200	200	200
Sub-base																				
Ditch left																				
Ditch right																				
Sveaskog																				
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				
Roadscanners																				
Wearing course	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base	100	100	100	100	100	100	200	200	200	200	200	100	100	100	200	250	250	250	250	250
Sub-base																				
Ditch left	[redacted]																			
Ditch right	[redacted]																			

SECTION 1/000-2/000 M

Dimensioning proposals for Timber road, length 5 km, width 4,5 m; layer thickness in millimeters

COMPANY	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900	1950	2000
Swedish Forest Agency																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	250	250	250	100	100	100	100	100	100	100	100	100	100	100	100	250
Sub-base																				
Ditch left																				
Ditch right																				
SCA Forest AB																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	200	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Sub-base																				
Ditch left																				
Ditch right																				
Sveaskog																				
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				
Roadscanners																				
Wearing course	150	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base	250				200	200	200	200	200	100								100	100	100
Sub-base																				
Steel reinforcement						10	10													
Ditch left	[redacted]																			
Ditch right	[redacted]																			

SECTION 2/000-3/000 M

Dimensioning proposals for Timber road, length 5 km, width 4,5 m; layer thickness in millimeters																				
	Road sections																			
COMPANY	2050	2100	2150	2200	2250	2300	2350	2400	2450	2500	2550	2600	2650	2700	2750	2800	2850	2900	2950	3000
Swedish Forest Agency																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	250	250	100	100	100	100	100	100	100	100	100	100	250	250	250	250	250	250	100	100
Sub-base																				
Ditch left																				
Ditch right																				
SFA Forest AB																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Base course	100	100	100	200	200	100	100	100	100	100	100	100	100	100	200	200	100	100	100	100
Sub-base																				
Ditch left																				
Ditch right																				
Sveaskog																				
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				
Roadscanners																				
Wearing course	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base	100							100			100	100	100	200	200	200	200			
Sub-base																				
Ditch left	[redacted]																			
Ditch right																				

SECTION 3/000-4/000 M

Dimensioning proposals for Timber road, length 5 km, width 4,5 m; layer thickness in millimeters																				
	Road sections																			
COMPANY	3050	3100	3150	3200	3250	3300	3350	3400	3450	3500	3550	3600	3650	3700	3750	3800	3850	3900	3950	4000
Swedish Forest Agency																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	100	250	250	100	100	100	250	250	100	100	100	100	100	100	100	100
Sub-base																				
Ditch left																				
Ditch right																				
SCA Forest AB																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Base course	100	100	100	100	100	100	100	200	200	200	200	200	200	200	200	200	200	200	200	200
Sub-base																				
Ditch left																				
Ditch right																				
Sveaskog																				
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				
Roadscanners																				
Wearing course	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base						100				100	100	200	100	200	100	200	200	200	100	100
Sub-base																				
Ditch left																				
Ditch right																				

SECTION 4/000-5/000 M

Dimensioning proposals for Timber road, length 5 km, width 4,5 m; layer thickness in millimeters																				
	Road sections																			
COMPANY	4050	4100	4150	4200	4250	4300	4350	4400	4450	4500	4550	4600	4650	4700	4750	4800	4850	4900	4950	5000
Swedish Forest Agency																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Road base	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Sub-base																				
Ditch left																				
Ditch right																				
SCA Forest AB																				
Wearing course	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Base course	200	200	200	200	200	200	200	100	100	100	100	100	100	100	100	100	200	200	200	200
Sub-base																				
Ditch left																				
Ditch right																				
Sveaskog																				
Wearing course	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Road base	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Sub-base	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Ditch left																				
Ditch right																				
Roadscanners																				
Wearing course	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Road base	100	100	100			200	100	100				200	200							
Sub-base																				
Ditch left																				
Ditch right																				

ROADEX

Implementing Accessibility

ROADEX PROJECT REPORTS (1998–2012)

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

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

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