Typical drainage problems in Northern Europe and the effect of improving drainage

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ABSTRACT: Typical drainage problems in the Northern Periphery area of Europe have been addressed in this paper. Field observations for roads on sloping ground shows large differences in rut depth and roughness on the road cut side compared to the embankment side. The road cut lane has the ground water table much closer to the road surface and therefore also a higher moisture content in the road structure materials and the subsoil. For 20 % of the analysed roads the rut depth on the road cut lane is 1.5 times larger than on the other lane. Just 12 % of the roads have larger rut depth on the embankment lane.
Predictions models are used to demonstrate the change in lifetime (calculated as number of standard axles) as a function of moisture content. Both field observations and prediction models show that improving the drainage will give a large profit in lifetime and also the life cycle costs. These are calculated for a period of 50 years and the conclusion is that maintaining and improving the drainage system is cost effective and must be prioritised among other maintenance activities. The first step in strengthening a road should be to make sure that the drainage system work properly and should be improved 1-2 years before paving.

KEY WORDS: Drainage, LCC, Roadex, Moisture,

1 INTRODUCTION

The ROADEX project is focusing on low traffic volume roads in the Northern Periphery of Europe (figure 1) and the aims, among others, are to create and share road and transport solutions that are economic and sustainable over the long term and to provide long-term maintenance options and the consequences to decision-makers.

Inadequate drainage is a problem that has been addressed in this project and some of the findings are presented in this paper.

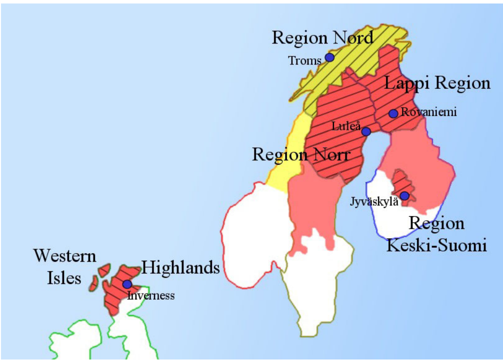

Figure 1: Partner districts in ROADEX II

2 PROBLEMS CAUSED BY INADEQUATE DRAINAGE

Drainage in road construction is a complex topic. This paper focuses on the problems that inadequate drainage causes with relation to lifetime for the road surface and compares this to the lifetime when the drainage system is working as planned.

Drainage of water from the road surface is also an important topic. First of all this water creates safety problems due to reduced friction on a wet pavement, but also splash and spray from the traffic is a problem. Furthermore surface water will infiltrate the road structure through cracks, potholes and unpaved road shoulders and then moisten the unbound granular materials in the road structure.

The problem is more complex in cold areas because freeze/thaw-cycles affect the moisture content to a much greater extent than elsewhere.

It is a well known fact that increased moisture content reduces the bearing capacity of a soil. This causes increased rates of deterioration and a shorter lifetime for the road surface and the needs for rehabilitation are greater than for a well drained road structure.

Funding for road condition management been decreasing in all the countries, that participate in the ROADEX project, for several years and the problem is that maintaining the ditches and the rest of the drainage system has not been prioritized. Instead of drainage maintenance the prioritized tasks have been those that are important to the road users in the short term i.e. repaving and snow clearing.

Knowing the effect of improving and maintaining the drainage system is important and, in this paper, observations and models have been used to estimate the increase in lifetime. The life cycle costs have also been calculated.

The Roadex analysis results demonstrate clearly that improving the drainage and maintaining it on a well performing level are very profitable measures, if the deterioration of the road can be attributed to the lack of a properly functioning drainage system.

3 MOISTURE CONTENT IN THE ROAD STRUCTURE AND THE EFFECT OF MOISTURE ON MATERIAL PROPERTIES

The moisture content in a road structure varies throughout the year. In summer, the moisture content in the road structure decreases slowly and starts to rise again in fall, because of increasing precipitation. During the winter unfrozen moisture content reaches its lowest value and in the springtime when the road structure starts thawing the moisture content increases rapidly. Moisture content becomes stable again at the end of summer. Possible peaks in the moisture content diagram are usually due to rainfall or winter and spring thaw.

Currently, time domain reflectometry (TDR) is the most popular technique used to measure the moisture content of soil in field tests. Other methods that can be used to measure moisture content in the soil are capacitance-based sensors, nuclear gauges, nuclear magnetic resonance (NMR) and ground penetrating radar (GPR). The TDR technique is based on transmitting an electromagnetic pulse through the soil and recording the resulting changes in its permittivity (dielectric constant). Change in the permittivity or dielectric constant is a measurable property and is related to the volumetric water content of soil. (Svensson, 1997).

The TDR technique and the Percostation technique (Saarenketo and Aho 2005) enable the continuous monitoring of variations in moisture content. Combining this data with back-calculated FWD data or DCP data permit the examination of the relationship between E-modulus, CBR values and moisture content for different soils.

Numerous laboratory research results concerning the correlation between resilient modulus, permanent deformation and moisture content have been published (see Bertnsen and Saarenketo 2005). The resilient modulus for an unbound material is mainly influenced by the stress state, dry density and moisture content. Soil suction is one of the parameters that define the stress state in unsaturated soils and also how the moisture content varies with the change in soil suction. Some researchers are of the opinion that suction describes the mechanical behaviour even better than moisture content.

The relation between suction and moisture content for an unsaturated soil is defined by the soil water characteristic curve (SWCC). When wetting or drying this curve does not give the correct matric suction due to the effects of hysteresis.

An example of an SWCC is shown in figure 2. The moisture content (W) decreases when the suction increases. Increased suction increases the bulk stress as well as the resilient modulus and shear strength.

Using the example above it is easy to understand that lowering the ground water table will benefit the bearing capacity for the unsaturated soils. Lowering the ground water table by ΔH increases the suction and thereby the effective stress in the material. The red arrows show the changes in moisture content.

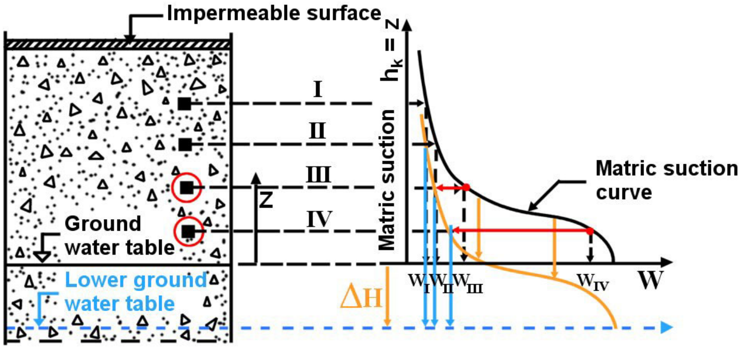

Figure 2: Soil water characteristic curve

Understanding figure 2 is essential to understanding why drainage is important. The goal is to keep the ground water table as low as possible. When an unsaturated soil is moistened, the hysteresis effect moves the curve for moisture-suction relationship above the soil water characteristic curve. This means an increase in moisture content which will certainly be the case when water infiltrates the road structure through cracks and potholes in the pavement layer or through the unpaved road shoulders. It is therefore important to seal the cracks, patch the potholes and have a correct transverse crossfall on the road surface to drain the surface water into the ditches.

4 CLASSIFICATION OF DRAINAGE PROBLEMS

The drainage problems in the Northern Periphery (NP) area were mapped using a questionnaire. Even though the ground conditions, landscape and climate varies a lot in the NP-area, the drainage problems are pretty much the same. The problems are grouped in three main categories as shown in figure 3, the overall problem is the high ground water table and problems related to rain and melting snow. Problems caused by high ground water table are addressed in the following.

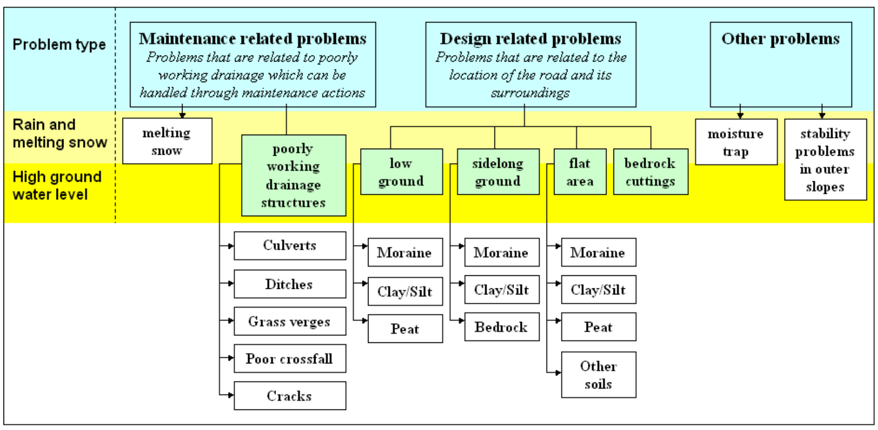

Figure 3: Category of drainage problems

5 MODELS PREDICTING THE EFFECTS OF DRAINAGE

Most design systems assume that the drainage system is working. This might be correct when constructing a new road, but when strengthening an old road this is not the case. Some design guides take into account the effect of drainage. In this study the Swedish design guide and the ASSTHO design guide have been used to illustrate the effect. For both guidelines the quality of the drainage are classified and the material property (elastic modulus) depends on this classification.

The Swedish design guide uses three categories to define how well the drainage system works. Class 1 is a well working drainage system and class 3 is a drainage system that is insufficient. The E-modulus depends on the season and the material type. The year is divided into 6 seasons and the length of each season depends on the climate.

Design system software, "PMS Object", can be downloaded from the Swedish Road Administrations web pages www.vv.se. The program uses a linear elastic model to calculate stresses, strains and the number of standard axles to failure. Fatigue in the asphalt layer and deformation in the subgrade are the two failure mechanisms upon that are considered.

The figures below show two examples of the effect of improving the drainage system from class 3 to class 1 on two normal road structures.

Example 1:

- 40 mm wearing course of bitumen + 70 mm asphalt as strengthening
- 120 mm bituminous macadam
- 800 mm old sub-base gravel material
- silt in the subgrade

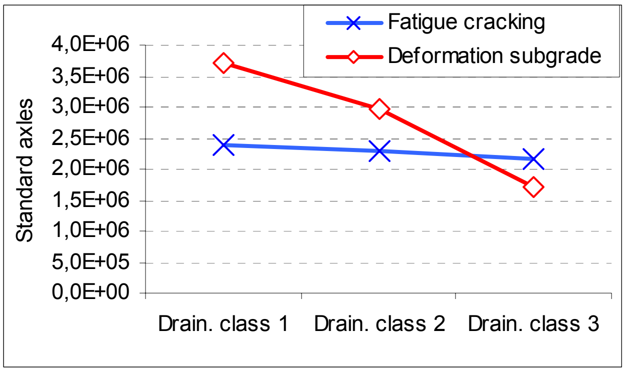

Figure 4: Standard axles - example 1

Example 2:

- 40 mm wearing course of bitumen
- 120 mm bituminous macadam
- 500 mm old sub-base gravel material
- moraine (type 3)

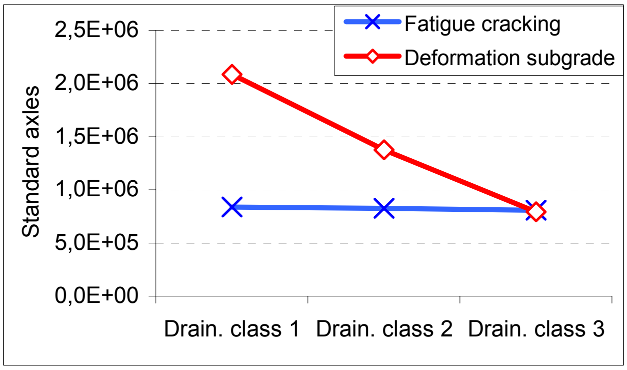

Figure 5: Standard axles - example 1

The deformation in the subgrade is most affected. The lifetime in example 1 will increase about 2.2 times and in example 2 by 2.6 time only by improving the drainage to class1.

The effect on fatigue cracking is only 10 % and 4 % in increased lifetime.

The equation for calculating the change in standard axles as a function of vertical strain in the subgrade is: $\frac{N_{undraind}}{N_{draind}} = \left(\frac{\varepsilon_{t-undraind}}{\varepsilon_{t-draind}}\right)^{-b}$

The Swedish design guide uses b=4. The parameter 'b' depends on the subgrade materials, but b=4 is often use for fine graded soils.

If this equation is used when calculating the affect of drainage using the AASTHO design guide, the calculated effect on the lifetime will be much larger than that calculated using the Swedish design guide, but the results are not presented here.

The soil water characteristic curve (SWCC) for typical subbase gravel materials is analyzed by Noss (1972). If this information is available, it is possible to determine the moisture content when changing the ground water table. If the relation between moisture content and elastic modulus for a specific material is known, the change in lifetime can be calculated in the same way as the Swedish design guide by calculating the strain in the subgrade.

Lary and Mahoney (1984) have investigated the resilient modulus for different materials. Their results show that the modulus is a function of moisture content, dry density and the sum of principal stresses. If the stress state and dry density is constant then only moisture content affects the modulus.

The SWCC for subbase materials and the equation for a water susceptible material are used in the example below to demonstrate the effect of lowering the ground water table from 20 cm above foundation level to 20 cm below. The subsoil in this example is silt.

Undrained construction.
Ground water table 20 cm above foundation level.

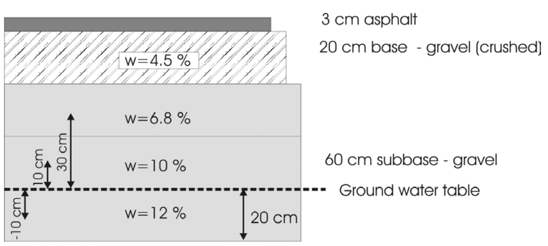

Figure 6: Road structure and ground water table - undrained condition

Drained construction.
Ground water table 20 cm below foundation level.

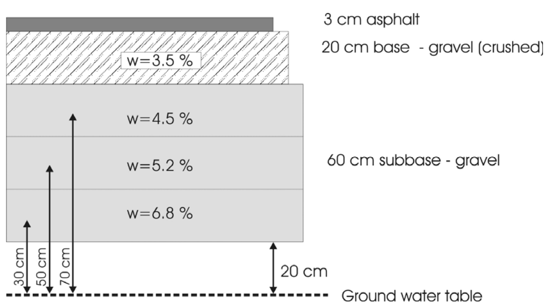

Figure 7: Road structure and ground water table - drained condition

The subbase is divided into three layers with different pore suction and moisture content.

The vertical strain on top of the foundation level is calculated using the computer program NOAH from Nynäs. NOAH uses linear elasticity in the calculations. The diagram in figure 8 shows the strains on top of the foundation level.

If the equation for relative change in N is used, bringing the drainage condition from wet to dry will increase the lifetime by a factor 1.74.

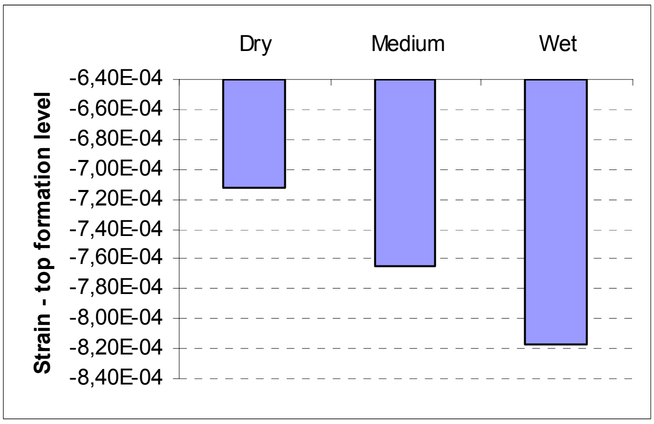

Figure 8: Strain on top of the foundation level

$$\frac{N_{drained}}{N_{undrained}} = \left(\frac{\varepsilon_{t-drained}}{\varepsilon_{t-undrained}}\right)^{-4} = \left(\frac{-7.12\cdot 10^{-4}}{-8.17\cdot 10^{-4}}\right)^{-4} = 1.74$$

This change in lifetime is only caused by the changes in the subbase materials. In addition there will also be a contribution from changes in the subgrade and the base layer due to reduced moisture content and this will also increase this ratio.

6 FIELD OBSERVATIONS

The models used in the previous paragraphs demonstrate that improving the drainage system will increase the lifetime considerably. Just by clearing the ditch the lifetime will increase at least 1,5-2 times. If the models are correct, a question arose, why is maintaining and improving the drainage system not prioritized by the road owners? This question was also addressed in the Roadex I project which showed that drainage was one of the biggest problems shared by the road regions of the Northern Periphery.

In order to verify the calculations the Roadex II project also made field observations and analyzed the data which further confirmed the change in lifetime when the lifetimes of a well drained road and that of a road with insufficient drainage were compared. This is demonstrated in the following examples.

6.1 Sloping ground

In some parts of the Northern Periphery area the roads are constructed on sloping ground where one half of the road is situated in a cutting and the other half of the road is situated on an embankment as shown in figure 9.

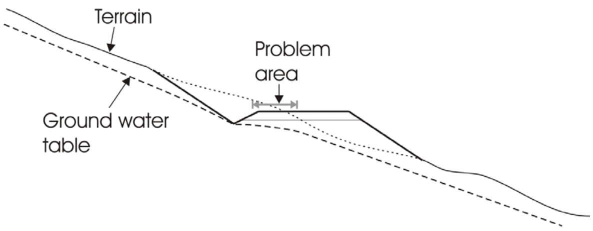

Figure 9: Drainage problem on sloping ground

The ground water table will normally be nearer to the road surface (and, as such, to the wheel load) on the road cut side. The moisture content is a function of the distance from the ground water table. When the ground water table rises the moisture content will increase according to the matric suction curve for the materials in the road structure.

This problem occurs normally in moraine and sand/silt materials. When there is clay or peat in the ground, the terrain is normally flat.

5.1.1 Example 1. Rv-858, Troms County, Norway

The first example where this problem can be observed, is national road RV-858 in Troms County, Norway

The rut depth is shown in figure 10. Rut depth is plotted for every 20 meter, but these lines are difficult to read so the average of one measurement in centre and 5 measurements before and 5 after this measurement are plotted with thicker lines. (Floating average of

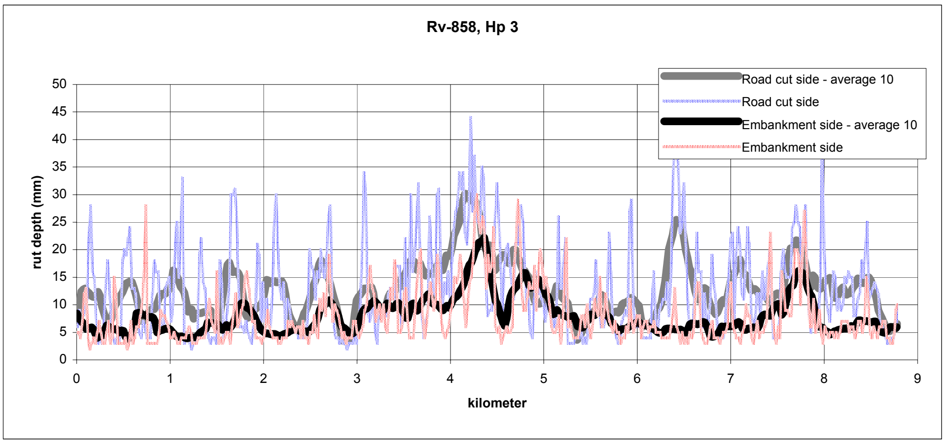

Figure 10: Ruts on both sides of the road. Example, Rv-858, Norway.

11 points.)

The light grey line represents the cutting lane and the black line the embankment lane. The average rut depth for the road cut lane is 12.9 mm and for the embankment lane 7.9 mm. The road was repaved in 1991-93 and is a road with relatively good bearing capacity.

After repaving there is normally 3-4 mm of rutting caused by the stresses from the construction traffic. The road cut side has developed about 1 mm rut each year while the rut depth on the other side has only increased approximately 0.4-0.5 mm each year. The consequence is that the road cut side triggers the need for rehabilitation many years earlier than the well-drained embankment side. The lifetime ratio (drained lane/undrained lane) is more than 2.

5.1.2 Example 2. Rv 861, Troms County, Norway.

The next example is from the road Rv-861 on the island of Senja in Norway. The diagram in figure 11 illustrates the problem. This road was repaved in 1991 and the right lane has an average rut depth of 21.6 mm while the other lane has an average of 12.7 mm. In this section, 10 % of the right lane had ruts deeper than 33.9 mm. In the left lane 10 % had ruts deeper than 23.4 mm.

In this section 10 % has worse IRI than 5.50 mm/m on the road cut side and for the other lane 3.60 mm/m. This also shows that the roughness is worse in the road cut lane.

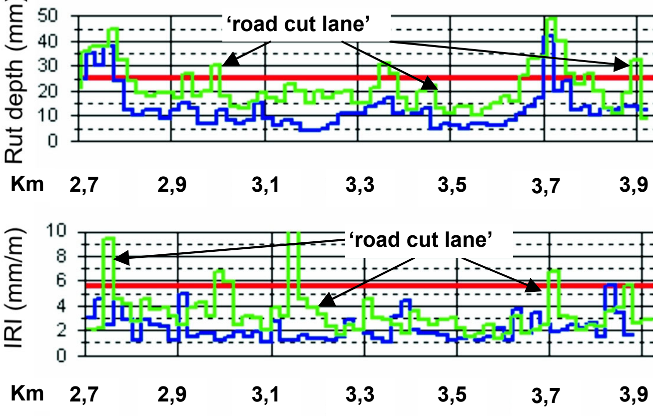

Figure 11: Example 2. Rutting and IRI Rv861

The upper lane develops, on average, 3.1 mm of rutting every year and 2.0 mm on the other side if it is assumed that 3 mm of rutting occurred just after the last repaving. It has also been assumed that the increase in rut depth is linear with time. The well-drained lane will then have a functional lifetime of 11 years and the other side only 7.1 years and this produces a ratio of 1.55.

5.1.3 Example 3. HW 21 (E8), Kilpisjärvi, Finland

This problem is not a typical Norwegian problem, but Norway records the rut depth of all paved roads every year in both directions, and has good statistics regarding these kinds of problems.

In Finland, the same problem was observed near to Kilpisjärvi on HW 21 (E8) not too far from the Norwegian border.

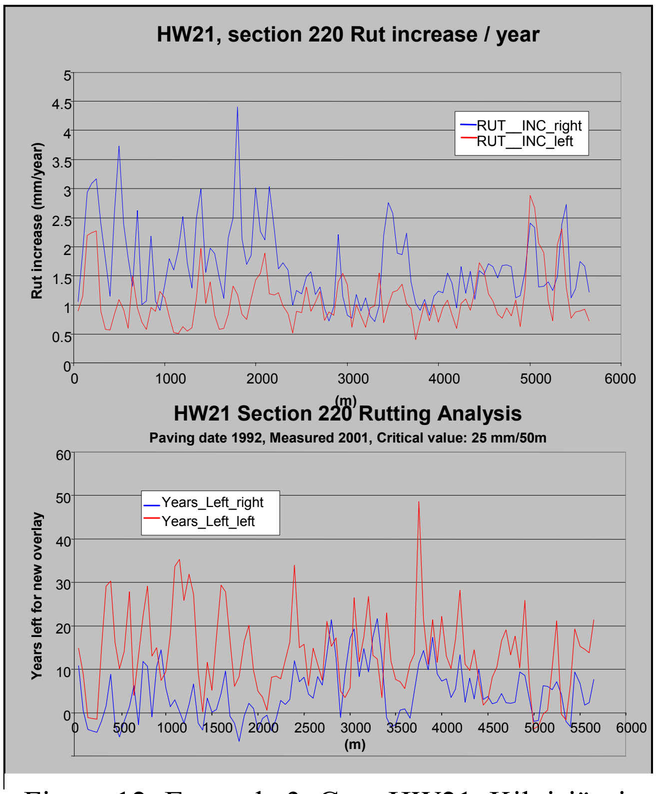

Figure 12: Example 3, Case HW21, Kilpisjärvi

Figure 12 shows the average rut depth progression for both lanes and in section 0-2500, where the ground slope is the steepest; there is clearly a difference in rut development.

The road was paved in 1992 and the rut depth was recorded in 2001. The remaining lifetime for the lanes is also illustrated in figure 12.

If only section 0-2500 is examined, the annual increase in rut depth is 2.0 mm in the right lane and only 1 mm in the left lane. This indicates that the lifetime is twice in the well drained lane if rut depth development is linear.

The rut depth measurement was measured when the pavement was 9.5 years old and the calculated remaining lifetime for the right lane was 1.8 years and for the left lane 15.0 years. In other words the lifetime for the left lane was 24.5 years and 11.3 for the right lane. This gives a ratio of 2.17.

5.1.4 Investigation of 184 km county road on sidelong ground

Figure 13 shows the cumulative distribution of the rut depth ratio for the well drain and undrained side of the road for 4 county roads on sidelong ground with a total length of 184 km.

Only 12 % has a greater rut depth on the well drained side of the road, 19.5 % has a rut depth ratio greater than 1.5 and for the rest (68.5 %) this ratio is between 1.0 and 1.5.

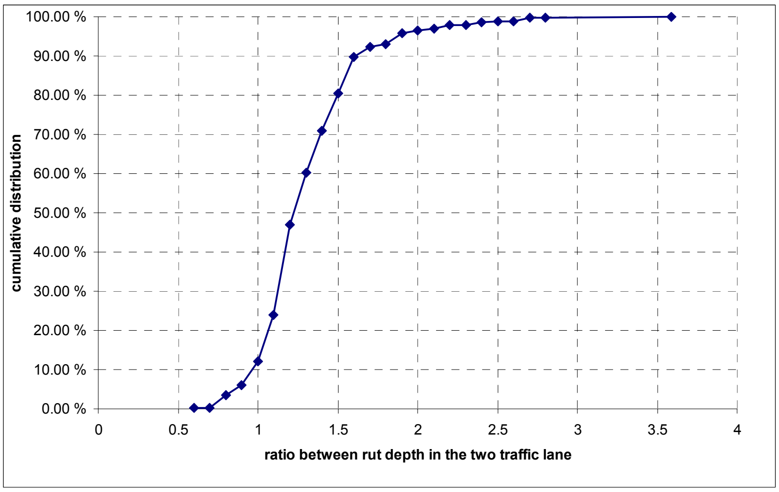

Figure 13: Cumulative distribution of the ratio for rut depth in the drained and the undrained lane.

6.2 Bedrock blocking water flow

Ground water will flow under the road and if there is bedrock or impermeable materials near the road area, these objects may block or concentrate the ground water to places where the potential for developing frost heaves, spring thaw softening and reduced bearing capacity due to high moisture content is high.

Figure 14 shows back-calculated values for the E-modulus from a site where the bedrock blocks the ground water flow. It can be seen clearly that the E-modulus are significantly lower than for the rest of the road section. The E-modulus for the asphalt layer is also much lower in this spot and the reason is probably that micro cracks already have developed in the asphalt due to a

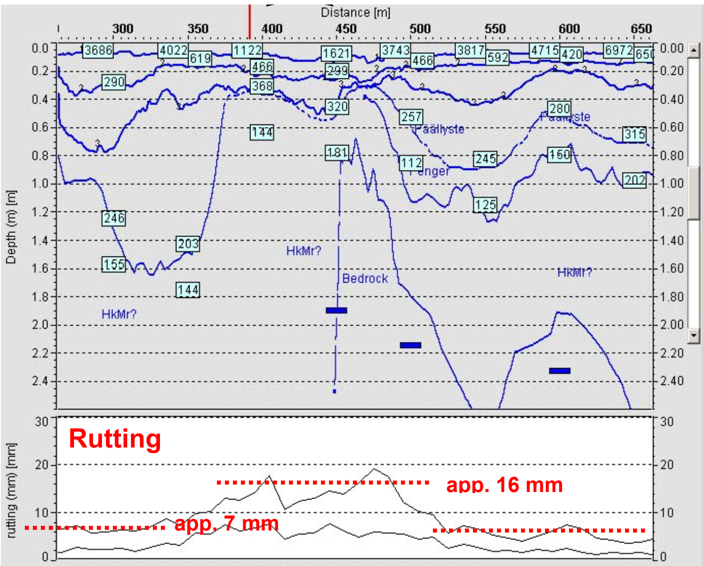

Figure 14: Low E-modulus caused by bedrock blocking ground water flow

weaker road structure. The materials in the road structure for the problematic spots are the same as for the rest of the road and therefore the changes in bearing capacity must be as a result of different moisture content.

The measured rut depth is also shown in the figure. The rut depth in the moistened section is about twice that of the of the rest of the section and will have just half of the lifetime

6.3 Road cuts and embankments

Figure 15 shows the results of an analysis of 155 km of low traffic volume national roads in Norway The roads' cross section is recorded for every 500 m and the average rut depth for 100 m on each side of the recorded section is used as rut depth in the diagram. The average rut depth increase (mm/year) is determined for sections where there are ditches on both sides, where there is ditch on only one side and where the road is located on an embankment (no ditches).

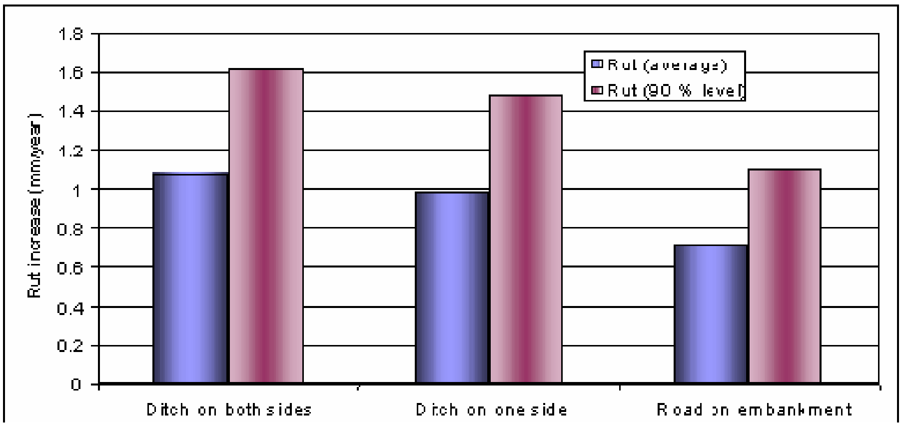

Figure 15: Rut depth progress depending on cross section.

The lifetime for roads on embankment is 20 years and in road cuts only 13.7 years. (Ratio=1,46). It is not only the ground water level that explains this difference, because the materials beneath the foundation level are not necessarily the same.

7 COST BENEFIT AND CONCLUSION

The field observations confirm the models used in this paper. Where inadequate drainage is the cause of road condition problems, improving or maintaining the drainage system will increase the lifetime by a factor of at least 1.5-2.0.

In the analysis of life cycle costs the focus has been on the repaving cost, cost for drainage improvements and maintenance cost for the drainage system. The road user costs and the environment costs have not been considered. The period of the analysis was chosen to be 50 years. Figure 16 shows how the calculation of the present value is done with and without drainage improvement. (Red colour indicates drained condition).

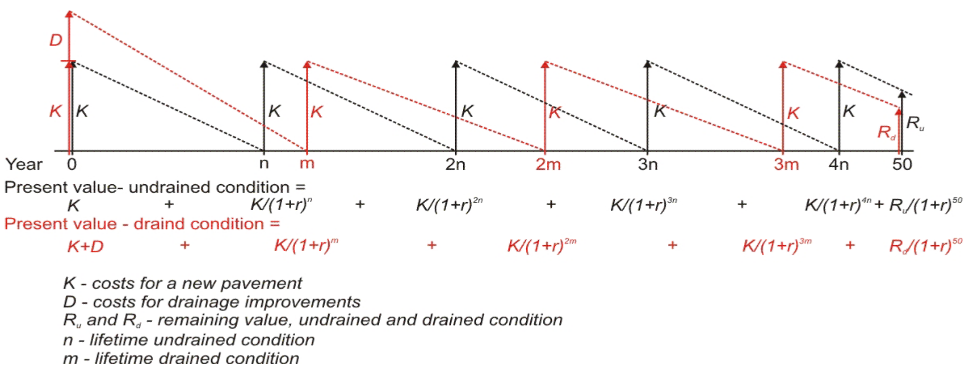

Figure 16: Calculation of present value

The Life Cycle Cost (LCC) is defined as present value of all cost between year 0 and N with year 0 as basis of comparison. The repaving costs, costs for drainage improvements and maintenance and discount rate differ markedly between the Roadex partner countries.

The drainage cost is normally 10-14 % of the pavement replacement cost on a low traffic volume road. The question is how often can drainage maintenance be done while still being profitable over the long term?

As an example a drainage cost of 4.100 €/km and a pavement replacement cost of 35.000 €/km (ratio 0.117) have been used. If improving/maintaining the drainage doubles the lifetime (from 10 to 20 years), then drainage maintenance can be done every second year and this will still be profitable even though the discount rate is as high as 8 %. If the increase in lifetime is only by 50 % (from 10 to 15 years) and the discount rate is only 4 %, then drainage maintenance can still be done every third year. Normally there is no need for doing drainage maintenance more often than this.

In this paper, it has been demonstrated thru models and field observations that if inadequate drainage is the reason for low bearing capacity and a short lifetime, then it is possible to increase the lifetime at least by a factor of 1,5-2 by improving the drainage. Having a well working drainage system will therefore be profitable.

The conclusion is that maintaining the drainage system is perhaps the most profitable maintenance task for road owners and that, in a sustainable and economical road condition management policy, effective drainage maintenance should be prioritized ahead of many other measures.

REFERENCES

Bertnsen, G. and Saarenketo. T., 2005 *Drainage on Low Volume Roads*. Roadex II Project Report. www.roadex.org

Saarenketo, T. and Aho, S. 2005. *Managing Spring Thaw Weakening on Low Volume Roads.* Roadex II Project Report. www.roadex.org

ATB-väg. *Swedish design guide*. Swedish Road Administration.

Noss, P. M., 1978. *Poresug i jordarter (Soil suction).* Thesis for the doctorate. Norwegian University of Science and Technology. Trondheim.

Berntsen, G., 1993. *Reduksjon av bæreevnen under teleløsningen*. Thesis for the doctorate. Norwegian University of Science and Technology. Trondheim.

Lary, J.A. and Mahoney, J.P., 1984. *Seasonal Effects on the Strength of Pavement Structures*. Transportation Research Record No. 954, Transportation Research Board, National Research Council, Washington, D.C.

Svensson, J. 1997. *Moisture content in road pavements, state of art and development of a simple moisture measurement equipment*. VTI meddelande 809A.