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ROADEX III
NORTHERN PERIPHERY

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MANAGING PEAT RELATED PROBLEMS ON LOW VOLUME ROADS

Executive Summary

Managing Peat Related Problems on Low Volume Roads
EXECUTIVE SUMMARY
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PREFACE

The report that follows is an executive summary of the two ROADEX II reports "Dealing with bearing capacity problems on low volume roads constructed on peat" (Munro 2005) and "Guidelines for the risk management of peat slips on the construction of low volume/low cost roads over peat" (MacCulloch, 2006), both of which are available on the ROADEX website.

The report draws on both documents, discussing the main issues to be considered when planning rehabilitation measures for floating roads over peat and offering guidance to recognisable problems where possible.

It aims to be a working manual concentrating on the main factors that have to be considered. It is not intended to replace the many excellent reference works or text books available on the subject but it is hoped that the various summaries outlined will give the reader a greater understanding of the opportunities, as well as the pitfalls, offered through using insitu peat substrates

The joint authors are practicing engineers based in the Highlands of Scotland – an area with an abundance of peatlands. Mika Pyhähuhta of Laboratorio Uleåborg designed the graphics layout.

The authors would like to thank the ROADEX III Steering Committee for its encouragement and guidance in this work.

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Chapter 1. INTRODUCTION

1.1 THE ROADEX PROJECT

The ROADEX Project is a technical co-operation between roads organisations across northern Europe that aims to share roads related information and research between the partners.

The Project was started in 1998 as a 3 year pilot co-operation between the roads districts of Finnish Lapland, Troms County of Norway, the Northern Region of Sweden and The Highland Council of Scotland and this was later followed up with a second project, ROADEX II, from 2002 to 2005.

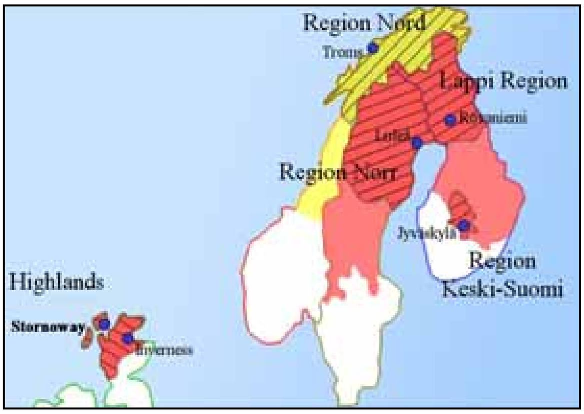


Figure 1.1 The Northern Periphery Area and ROADEX II partners

The partners in the ROADEX II Project comprised public road administrations, forestry organizations, forest companies and haulage organizations from regions in the Northern Periphery. These were The Highland Council, Forest Enterprise & The Western Isles Council from Scotland. The Region Nord of The Norwegian Public Roads Administration and The Norwegian Road Haulage Association, The Northern Region of The Swedish Road Administration and The Lappi and Keski-Suomi Regions of The Finnish National Roads Administration. (These latter Finnish Regions also received aid from their local forest industry organisations of Metsähallitus, Lapin Metsäkeskus, Metsäliitto & Stora-Enso.)

The goal of the project was to develop ways for interactive and innovative road condition management of low traffic volume roads integrating the needs of local industry, society and roads organisations. Eight formal reports were published together with a project DVD and full copies of all reports are available for download at the ROADEX web site at www.roadex.org.

This Executive Summary report is one of 8 summaries that have been prepared under the direction of the ROADEX III project (2006-2007), a new Project where the named project Partners above were joined by the additional Northern Periphery Partners of the Municipality of Sisimiut, Greenland, The Iceland Public Roads Administration and the Finnish Road Administration Region of Savo-Karjala.

1.2 ROAD CONSTRUCTION OVER PEAT

The construction and maintenance of roads over peat tends to be considered as a 'black art' by many engineers. As a consequence a great number of engineers, without peat experience, tend to avoid construction risk and opt for safer, more conservative forms of construction whereby any peat found on the route of a road is totally removed and replaced with clean, sound, road foundation material. This practice however ignores some very good practices developed over long periods of time in Northern latitudes and is an expensive solution, as well as being a primary user of scarce natural resources, and only really affordable in the construction of high speed national roads.

Lower classes of roads, and particularly low volume roads, can realise real benefits from retaining peat as a subgrade (benefits such as economy, environmental sustainability, lesser use of materials, etc) and develop more cost effective and site specific solutions than simply always digging out the material and throwing it away. This is especially the case in rehabilitation projects of roads 'floating' on peat where it is unlikely that a simple solution of full excavation, a re-alignment or a local diversion is possible. If it was, the original designers of the road would probably have done it in the first place.

Decreasing national roads budgets, and the need to get more road kilometres per Euro, now provide the impetus for conservative construction practices to be re-examined. The bearing capacity problems of roads over peat were identified as a common problem across the Northern Periphery in the ROADEX pilot project and the subsequent ROADEX II report "Dealing with bearing capacity problems on low volume roads constructed on peat" (Munro 2005) reviewed the state of the art in road construction over peat in the partner areas.

This report will look at the difficulties of rehabilitating existing roads over peat, primarily the so-called "floating roads", and discuss how modern survey, monitoring and construction practices can assist engineers in assessing and evaluating problem road sections so that 'fit for purpose' solutions can be developed and implemented without the need to resort to excavation in all occasions.

The report will summarise the main issues to be considered when planning these types of works and offer guidance to recognisable problems where possible. Its aim will be to be a practical guide for the local road maintenance engineer/ designer that can be used to address the common problems raised by roads over peat subgrades.

Chapter 2. INITIAL CONSIDERATIONS

Peat is not a uniform material and a basic understanding of its properties is required before a solution can be considered.

2.1 FORMATION OF PEAT

The term ‘peat’ can cover a wide range of organic soil types but for the purposes of this report ‘peat’ will be limited to the high vegetable material that forms in waterlogged areas when the natural processes of plant decay fail to keep up with the amount of vegetation being produced. In the Northern Periphery there are 4 main types of peat landscape recognised:

- Mires – where the peat is currently forming and accumulating and has not yet reached the stage of a true peat
- Fens – where the established peat obtains its water and nutrients from the soil, rock and groundwater as well as from rain and/or snow
- Bogs – where the established peat receives its water solely from rain and/or snow falling on its surface
- Blanket bogs – where the peat covers the land like a carpet

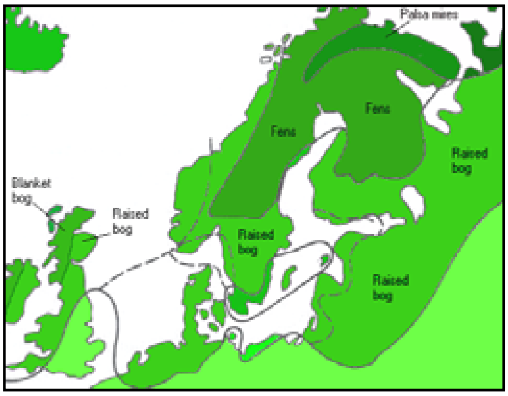


Figure 2.1 Mire zones across northern Europe Succow & Jeschte 1990

These trans-national peat landscapes give rise to many common problems to roads maintenance authorities across the Northern Periphery and the lessons learned, and good working practices developed, by one organization can be shared with others without the necessity of the lessons being re-learned again.

The range of landscapes and peat formations do however give rise to a range of different peat types. Within each landscape the insitu peat can be highly variable in character due to the way that it has been formed as well as being highly variable in properties within each deposit, both horizontally and vertically. It is therefore important to develop an understanding of how the particular peat is growing on site, its “geomorpohology”, in order to determine its basic engineering properties of interest to the engineer.

2.2 BASIC PROPERTIES OF PEAT

Peat is considered to fall into 3 main groups for engineering purposes: ‘amorphous-granular peat’ (ie well decayed peat), ‘fine fibrous peat’ and ‘course fibrous peat’

(Radforth, 1969). The amorphous-granular peats have high colloidal mineral elements and tend to hold their water locked in an adsorbed state around the grain structure like clay. The two fibrous peat types, 'fine-fibrous' and coarse-fibrous', are woodier and hold most of their water within the peat mass as free water. These basic groups generally reflect how the peat deposit grew and govern the main engineering properties.

Insitu peat can be classified by 2 systems, both using a simple visual identification: a) the Radforth system, with the 3 main classes as above, and b) the Vost Post 'degree of humification' system that bases its classification on the state of the decay of the peat by means of descriptions of hand squeezing samples. Full details of these systems are given in the ROADEX II report "Dealing with bearing capacity problems on low volume roads constructed on peat" (Munro 2005).

High water content is probably the most distinctive characteristic of a virgin peat deposit apart from its high vegetable content and most of the basic engineering characteristics of peat as a foundation material result from this simple property. The shear strength of a peat deposit depends on its water content, degree of decay and mineral content. Shear strength is a key parameter for roads applications and normally the higher the water content of the peat the lower its shear strength, the more fibrous the peat the greater its shear strength, and the higher the degree of humification and mineral content of the peat the higher its shear strength. The strength of a peat in a particular deposit is seldom dependent on depth. Frequently a peat bog will show a strength decrease with depth due to the changing character of the peat particularly where it becomes less fibrous and more amorphous with depth.

1.4.2 Summary of typical peat properties

This table lists some of the more interesting engineering properties of a peat deposit, the most useful of which being the water content.

The results of a simple **visual classification** together with **water content** can give an indication of many of the important parameters of interest to the engineer and **both are recommended as a minimum** for works on low volume roads.

Property	Type of Peat		
	Fibrous peat	Medium decayed peat	Decayed peat
Water content %	1400 - 2500	900 - 1400	500 - 900
Ash content %	1.5 - 3.0	3 - 8	8 - 30
Void ratio	22 - 40	13 - 22	9 - 13
Shear strength (kPa)	5-15	5-15	5-15
Permeability (cm/sec)	10^{-3} - 10^{-4}	10^{-4} - 10^{-5}	10^{-5} - 10^{-6}
Insitu bulk density (kg/m³)	900 – 1100	900 - 1100	900 - 1100

Table 2.1 Summary of typical peat properties

2.3 BEHAVIOUR OF PEAT

Peat consolidates and settles under load and as a result needs to be loaded slowly, and permitted sufficient time to increase in strength, if it is to be used as a foundation material. If it is loaded too quickly it will shear and fail.

The construction of an embankment on peat when carried out slowly, squeezes and compresses the peat under the load, causing a greater part of the load to be taken on the vegetable matrix within the peat and this produces the consequent increase in strength in the loaded peat. Fuller details of this strengthening process are given in the ROADEX II report “Dealing with bearing capacity problems on low volume roads constructed on peat” (Munro 2005).

The usual form of a slow controlled consolidation of peat can be seen in the following graph of the settlement of an embankment over peat.

‘Primary consolidation’ normally takes place within the time it takes to build an embankment and its magnitude is dependant on the weight of the embankment and the thickness of the peat and any other compressible layers. Once this initial phase has passed settlement under load continues at a much slower ‘secondary compression’ rate, generally accepted to be linear with the logarithm of time.

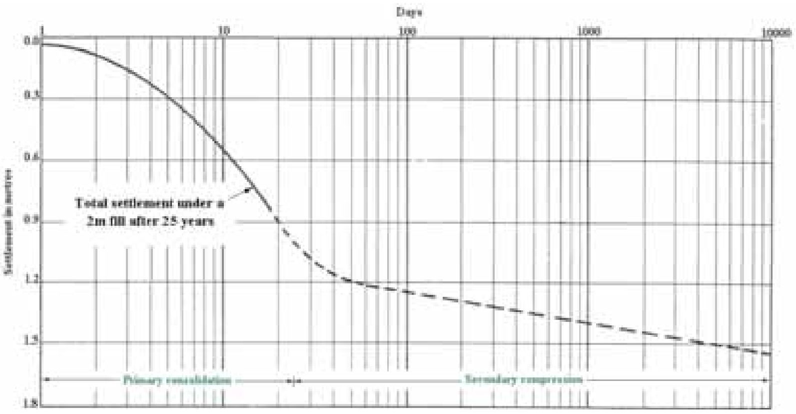


Figure 2.2 ‘Time v Settlement’ graph of an embankment on peat.
(The Muskeg Engineering Handbook. National Research Council of Canada)

What is not shown in the graph is the parallel increase in strength of the peat, with time and consolidation, as the peat compresses into a more compact volume. This feature should be kept in mind when considering maintenance and rehabilitation operations involving roads over peat. At any time a loaded peat will have reached a state of equilibrium under the load that it is experiencing. This will be a balance between the applied load, the degree of settlement reached, the increased strength of the peat matrix, the ground water table and any buoyancy effects. Any disruption to this state of partial equilibrium, such as with an additional loading of a new overlay or an alteration to the hydrology of the site through deepening ditches, will disturb the balance that has been created with time in the road/peat structure and cause a change to happen, normally a further consolidation and settlement. This is to be avoided of course, unless it has been designed into the rehabilitation measures and the resulting effect expected.

Chapter 3. THE REHABILITATION PROCESS

The rehabilitation of roads suffering from peat related problems has so far been a very local issue that has been generally based on the practical experience of the local engineers concerned without the benefit of sharing of experiences. This has produced some very innovative solutions by a number of engineers in certain areas but more usually has resulted in a single solution in an area that is used to fit all cases. This has not always resulted in long term, permanent solutions however and in some cases, where additional weight has been added during work, has even hastened the growth of the defects rather than getting rid of them.

This report will advocate a 5 stage process for the rehabilitation of floating roads over peat:

1. identify the underlying problem through appropriate surveys
2. analyse the survey information collected
3. select the most suitable rehabilitation measure
4. monitor the work during construction
5. record and share the results

Items 1 to 3 in this process may seem at first glance to be a cost that can be saved during times of limited funding but this would be a rash decision. The cost of survey, analysis and selection may constitute 2-4% of the overall funding of a project, depending on the size of the works, but it is money well spent in producing the most appropriate long term solution. The message from the ROADEX project is that sufficient resources should always be allocated to the diagnosis of the problems underlying damaged road sections. And in the context of this report this means that rehabilitation works involving peat should always be based on sound collected data.

It is worth mentioning here that any data gathered for a project is not just a “single-use” investment. All data, once collected, can be utilized in many ways for many years not only in the design and rehabilitation of roads but also in the performance management of the completed road structure and its service life. With good monitoring and record keeping the data collected can be kept on file for future works and used as a reference source, increasing the collected experience. Data collected now, and shared, can help current and future engineers to produce better, ‘fit for purpose’ designs and prevent them from falling into the trap of continually ‘re-inventing the wheel’ each time similar circumstances arise. Good data, well recorded and saved systematically, is important for survey, analysis, design, monitoring and records, now and in the future. With this in mind, it is recommended that all data should be saved with its linkages, GPS or similar, so that it can be re-accessed and assessed jointly again in the future.

Chapter 4 INVESTIGATIONS & SURVEYS

4.1 SITE INVESTIGATION METHODS

There is normally an economic limit to the amount of site investigation that can be carried out for low volume/low cost roads over peat due to budgetary and time constraints placed on the engineer.   A range of suitable survey methods for low volume roads is given in Table 4.1 below together with a short description of the information they can provide and further details regarding these techniques can be found in the ROADEX II project reports.

Table 4.1

Survey Method	**Description**	**Comment**
Desk study	Office based research into local maps, records, reports, network defects, maintenance histories as well as similar local projects, local peat properties, results of projects, etc.	Initial background research for the project to gather all relevant records together to enable project planning. **Essential**
Site Visit & Walkover	Visual inspection of the site by an experienced engineer with a previous experience of construction involving peat.	Practical, low cost survey to get an impression of the site and the difficulties it presents. **Essential**
Probing	Steel rods pushed into the peat to establish depth. Some form of probing exercise will be necessary in every project involving peat.	A simple, robust method for determining the depth of a peat deposit or as a calibration exercise for a non invasive survey method such as GPR. **Essential**
Ground Penetrating Radar, GPR	Increasingly used non invasive method for peatland surveys, particularly useful for establishing the thickness of the existing road layers and soils depths prior to widening and strengthening.	Radargrams can show clear boundaries between the road, underlying peat and rockhead and can be used to monitor the long term behaviour of the road with good accuracy. **Recommended**
Digital Video	Video recording of the visible infrastructure of the road referenced by distance from a common origin or by GPS.	The video recording produced that can be used as simply as a formal record or analysed further, eg drainage or distress evaluation. **Recommended**
Sampling	Invasive ground investigations for obtaining physical samples for use in determining the thicknesses and properties of the road structure and subgrade.	Coring & sampling can also provide useful data to calibrate and supplement other methods. **Some sampling recommended**
Penetration Testing	Similar to probing but with the probe measuring the relative stiffness and strengths of the layers that it passes through.	Can be a useful method when there are layers of peat and other materials below the road.
Falling Weight Deflectrometer, FWD	Non invasive testing equipment that simulates the load of a heavy vehicle on the pavement	Can give estimations of bearing capacity, subgrade soil, presence of peat layers and location of bedrock
Accelerometer/ Profilometer	Vehicle mounted sensors that quantify the roughness of a road through deflection and vibration measurements	

The first 2 methods listed in Table 4.1, the desk study and site visit, may appear at first reading to be simple exercises that can be omitted if funding is limited. This action however would be a false economy. A good desk study can produce valuable historical information on what has gone before such as road maintenance histories, records of similar local works, previous ground investigations, peat properties, availability of materials, etc, and these are vital if lessons are to be learned from past experiences.   All records of projects, whether good or bad, can add to the knowledge base for a project and can regularly trigger useful solutions if designers are open-minded.

The site 'walkover' survey for example produces the very practical result of a detailed picture and understanding of the surface features of the site, such as the extent of the peatland, the presence of any ditches, watercourses, subsurface pipes, surface topography, peat workings, waterlogged areas, areas of free water, etc.

Both the desk study and site walkover are vital precursors to the main site investigation and the subsequent analysis of the site but it will seldom be cost-effective to use all of the methods listed. It will normally be necessary to select the most appropriate combination of methods for a particular site to ensure that all of the relevant information is collected so that a proper analysis of the site can be made. It is, however, vitally important that sufficient information is gathered on which to base a design. Too often hard pressed engineers are tempted to omit the site investigation phase on the grounds of economy and speed. This is always a mistake. Rehabilitation works involving peat must be based on sound collected data.

ROADEX experience recommends a combination of 6 survey methods for peat related problems on low volume roads:

- A desk study
- A site visit & walkover
- Probing
- Ground penetrating radar, GPR
- Falling weight deflectometer, FWD
- Digital video

The ROADEX Project partners have found this combination of methods gives a sound base of factual survey information on which to establish appropriate 'fit for purpose' rehabilitation solutions.   With such information in place the next phase, an "integrated analysis", can be commenced to understand the underlying problems.

4.2 GROUND INVESTIGATIONS

As mentioned in Table 4.1 some ground investigation and sampling is recommended in works involving peat. Normally these are:

- Type of peat and degree of humification from sampling by screw auger
- Depth of peat by probing and/or GPR
- Bulk density and water content from undisturbed samples if possible

Undisturbed samples are difficult to obtain in peat due to its very high water content but a simple and effective sampler has been produced by the Swedish Geotechnical Institute. The "SGI sampler" has a sharp circular wave-toothed cutting edge mounted on 100mm diameter plastic tube capped with a robust driving head on top. The length of the tube is variable and dictates the length of sample recovered but normally a 1.0m long sampler is sufficient. The extent of disturbance in the sample largely depends on the method used to drive the sampler into the ground and it has been found that the best results are usually achieved when the sampler is driven down into the peat by means of a lightweight percussive machine or gentle tapping with a hammer. This type of low cost system is recommended for obtaining samples of peat on low volume roads.

Figure 4.1 Photographs of The Swedish Geotechnical Institute Sampler in use.
Source: Swedish Geotechnical Institute.

Chapter 5. INTEGRATED ANALYSIS

The ROADEX method of “integrated analysis” brings all of the relevant survey data together into one place for analysis and design. Combining the survey data in this fashion permits the project team the best possible opportunity to ‘diagnose’ the local underlying problems and their respective causes at the site by a) identifying the particular problem areas in each road section and focussing attention in on them, and b) facilitating the selection of the most suitable rehabilitation measure(s) for the sections in need.

A typical ‘integrated analysis’ screen, showing combined survey data, is given in Figure 5.1 using ‘Road Doctor’ software as manufactured by Roadscanners Oy of Rovaniemi, Finland. The screen shown presents the combined selected survey data for the roads section referenced to a common origin and/or GPS. It consists of from top right:

- 2 ground penetrating radar radargrams (data 1 and 2) with interpretations of the pavement layers, embankment thickness and depths of underlying soils (data 3). The thicknesses of the road construction layers can be particularly useful in the estimation of the current loadings on the peat subgrade and, by calculation, its current shear strength.
- Falling weight deflectometer test results (data 4). This data is useful in evaluating the stiffness of the road structure layers and determining whether the surveyed carriageway problems are related to the peat subgrade or other features.
- A series of interpretations of the data collected: the surface curvature index (SCI), the red column, giving an indication of the stiffness of the pavement and bound base layers (data 5), the base curvature index (BCI), the blue column, giving an indication of the load spreading capability over the weak subgrade (data 5), classifications of the various layers of the road (data 6-10), surface layers, unbound layers, subgrade, soil classification and an overall risk assessment of the section of road being considered.
- Digital video (data 11) which can be used for evaluating the overall site picture and peatland implications, the extent of the problem areas, any roadside drainage, infrastructure and properties that may be affected.
- A base map (data 12).

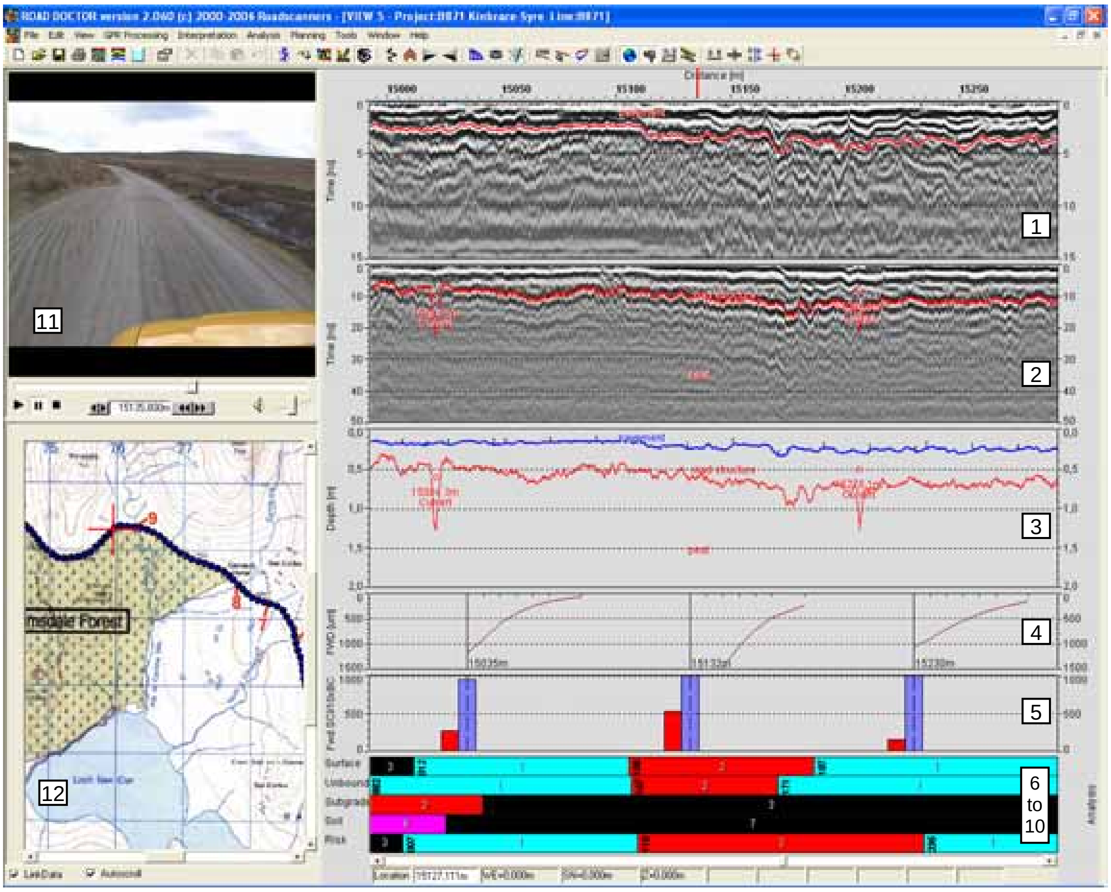


Figure 5.1 Road Doctor integrated analysis screen from the B871 public road, Scotland

(two GPR profiles, FWD deflection bowls and interpretation, base map and video, all to a common origin. This survey data was jointly used to carry out an assessment of the road layers and subgrade to produce a risk analysis of the road for the prediction the likely pavement damage ahead of timber haulage operations. The analysis process, reported in the ROADEX II project, was subsequently proved correct over 3 years of timber haulage.)

This form of 'integrated analysis' screen, showing the combined survey data, allows the design engineer to cross analyse all of the chosen data in one location without the complication of having to refer to numerous independent reports and sections with different referencing systems. This feature is a real strength of the 'integrated analysis' system and offers significant savings in time over traditional systems of analysis.

Additionally by knowing the precise location of the particular site and defects, and implementing precise rehabilitation measures based on their causes, unnecessary construction work and inappropriate rehabilitation actions can be avoided (Saarenketo 2001).

Chapter 6. REHABILITATION METHODS

6.1 BASIC CONSIDERATIONS

The overriding basic rule in any local road rehabilitation over peat is, in addition to trying to improve the existing circumstances, not to do any work to the existing road/peat balance that would cause further damage, or to put it more simply, 'to do no more harm'.

It is a positive feature of an existing road over peat, even one that has settlement problems, that the peat below the road has usually been loaded over time and increased in strength to support the general weight of the road. This increase in strength, essentially a 'preloading', can be used to advantage in the rehabilitation of a road, provided that nothing is done that would cause further consolidation being triggered unless by deliberate design where the consequences are known and accepted.

This is not always easy however as each road rehabilitation brings its own practical site management problems such as:

- Traffic management – dealing with the existing traffic flows along the road. This can involve road closure, single lane working, or the construction of a temporary bypass road if sufficient land is available alongside the existing road. The management of existing traffic flows may be a major consideration on the type of rehabilitation possible for a road section.
- Execution of the work – can the work be carried out within the available site and traffic management? A rehabilitation using steel grids for example needs to have the steel grid laid across the full width of road, approx 30cm deep, without a longitudinal joint. This may not be possible at the site with live traffic flows and a more suitable option may be to build on top of the existing road and accept the settlement that will happen. The eventual decision will be a balance of the available engineering solutions and effects.
- Construction vehicles. The effects of the heavy construction traffic on the excavated surfaces will need to be taken into account. Work cycles will have to be planned in detail to ensure that sufficient strength is retained in the remaining existing road layers to support the construction activities. Ground penetrating radar surveys carried out during the pre-project site investigation can help identify thicknesses and strengths of layers for this.

As a result it may be that on some sites that excavation into the existing road cannot happen and that rehabilitation measures will have to add layers to the road. In these cases additional load will have to be accepted, but its effects must be understood and expected by the designers of the rehabilitation. (A rehabilitation solution for paved roads that uses reinforced asphalt or bituminous overlays is discussed later within the report. This incurs settlement.)

In summary, the aim in rehabilitation works over peat should be to cause ‘no more harm’ unless the effects can be predicted and accepted. ‘Harm’ in the context of rehabilitation works means adding load or changing the hydrology of the road and surroundings to cause a lowering the ground water table

As already mentioned in Chapter 2, in the normal course of events a position of equilibrium quickly builds up between a road structure and the underlying peat whereby the peat gains sufficient strength through the release of porewater to support the weight of the road. After this early equilibrium has been achieved the road continues to settle over the longer term at a much slower ‘secondary compression’ rate. Any application of new load once the equilibrium has been established (such as with a new overlay) or a change to the water content of the peat (such as with deepening drains) will cause a disturbance that will restart the consolidation and settlement process over again.

In this scenario the lowering of the groundwater table will have the same effect as adding weight to the road. When the groundwater table is lowered within a floating road the hydrostatic uplift on the road, its “buoyancy”, is reduced and the drained road will, as a consequence, sit higher in the water table than previously. This effectively makes the road heavier than previously and results in a heavier load being placed on the underlying peat which causes further compression and settlement. This change in water level takes time of course, and does not happen as a single event, but the effect in the long term is the same. The load is increased and a settlement occurs. The mechanism at work can be illustrated in the following figure.

<u>Example:</u>
Bulk density of gravel, γ, **18kN/m³**
Saturated density of gravel, $\gamma_{s,,}$20kN/m³
Density of water, $\gamma_{w,}$ 10kN/m³
Density of saturated peat, 10kN/m³
Effective density of submerged gravel, γ'
$= \gamma_s - \gamma_w = 20 - 10 =$ **10kN/m³**

Difference in density = $\gamma - \gamma'$
= 8kN/m³

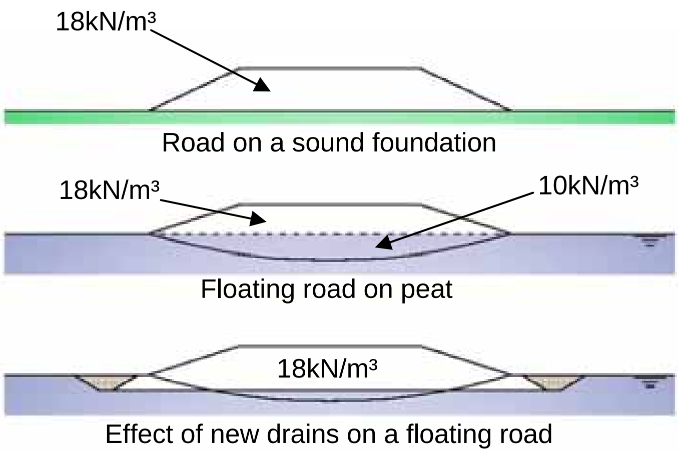


Figure 6.1 Buoyancy effects in floating roads (after Carlsten)

The top sketch In this example shows a road embankment constructed on a sound base layer with little or no settlement. Drainage measures have few adverse effects on this form of construction and in general are very positive. The middle sketch shows a typical ‘floating road’ over peat where the road has settled into the peat, the underlying peat has consolidated and buoyancy is having an effect. In this arrangement the effective submerged density of the embankment below the water table is reduced from 18kN/m³ to 10kN/m³ with a consequent reduction in load on the underlying peat. The bottom sketch shows the effect of lowering the water table by ditching (shown in grey) after the equilibrium position has been established. Here the lowering the water table reduces the established effects of buoyancy and increases the effective density of the embankment below ground level from 10kN/m³ to 18kN/m³ with a consequent increase in load on the underlying peat that invariably triggers a renewed settlement.

In this example lowering the water table by 1.0m by ditching will cause a potential increase in load of 8kN/m³ on the peat. Lowering the water table by a more modest 0.5m will cause a potential increase in load of 4kN/m³. These changes in water level will take time to happen of course, and the embankment will respond incrementally as the water table lowers, but the effect in the long term will be the same. The load on the underlying peat will be increased and a settlement will occur.

For this reason the ideal rehabilitation solution is one which will not produce any new loads on the peat nor change the established drainage regime – but, as already said, this is not always possible.

6.2 REHABILITATION MEASURES

This report will consider 4 common rehabilitation problems related to ‘floating roads’ on peat subgrades on low volume roads:

1. Carriageway settlement and irregularities
2. Embankment settlement, including raising the alignment
3. Road widening

The descriptions of these problems, and solutions offered, will try to work within the principle of ‘do no more harm’ already described. These general solutions will aim to result in rehabilitated roads that are the same weight, or lighter, than the former road. It is however accepted that this practice will not be possible in all projects and where it is not possible to excavate into the existing road the solutions presented will be able to be added to the existing road layers as overlays, adding height and weight to the road structure. In these cases settlement must be expected to happen.

6.2.1 Carriageway settlement and irregularities

Peat related problems in carriageways normally show up in a number of forms; uneven road surfaces, settlements and differential settlements, longitudinal and transverse cracking, edge deterioration, asphalt disintegration and others. These effects can be of varying degrees of severity and pose a range of hazards to traffic, resulting in increasing vibration, reduced comfort to drivers and reduced speeds. The immediate response of some authorities to such uneven roads is to try to reshape the carriageway by overlaying the irregular surface. This seldom works in the medium term, particularly with floating roads on peat, as the additional weight of the overlay layers placed on the road only increases the local load on the peat and this quickly produces further consolidation and settlement with the expected result - the irregularities in the carriageway reappear to their former condition, or worse. As an example, a 10cm rehabilitation overlay (approximating to 0.2 tonnes/m^2) can easily disappear in a year and the resurfaced road quickly return to its former condition before the rehabilitation. A rehabilitation solution for paved roads, that uses an additional reinforced asphalt or bituminous overlay, is discussed later within this section but this will incur a settlement. If the old pavement can be milled off before the new layer is placed this will not increase the weight of the road or trigger further settlement.

Rehabilitation measures therefore should be carried out within the existing weight of the road structure, and preferably less, if further consolidation and settlement is not to be triggered in the underlying peat. Ideally the rehabilitated road should be lighter than the former road to ensure success. Where it can be done 3 types of remediation measures are possible:

A. Where the problem can be limited to the construction layers (minor settlements, cracking, alligator cracking) and the rehabilitation can be accommodated within the road construction layers without adding additional load;
B. Where the problem is limited to the construction layers (moderate settlements, cracking, deformations) and the rehabilitation can be accommodated within the road construction layers with the use of lightweight material;
C. Where the problem is not limited to the construction layers (significant settlements, deformation, flooding) and the rehabilitation has to include the replacement of some, or all, of the road embankment with lightweight material.

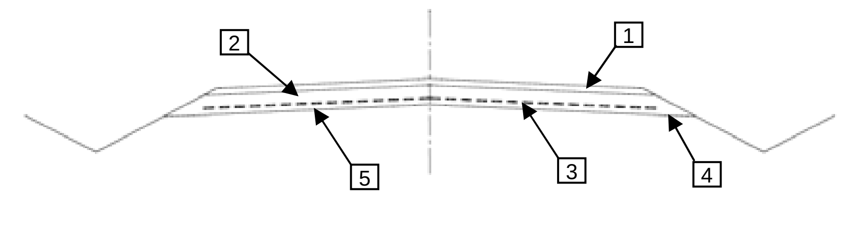
Case A: 'The Standard Structure'

The basic rehabilitation structure for case A, a road on peat exhibiting carriageway defects, is:

A – STANDARD REHABILITATION STRUCTURE

1. removal of old wearing course
2. removal of old material (to a depth to permit the new construction layers, ie 400mm in this example)
3. installation of a geotextile separator
4. provision of new unbound basecourse 100 mm
5. installation of new steel reinforcement
6. new base course material 200 mm
   new wearing course 100 mm (or a new flexible pavement layers for a paved road)

The depth of material to be removed from the road in this exercise should be the same as, or greater than, the sum of the new road construction layers. If this can be achieved the rehabilitated road should impose the same, or lesser, load on the subgrade. The geotextile separator in the structure should be selected to suit the basecourse material to be placed and strong enough to resist punching by the new aggregate.



No	Layer
1	Wearing course
2	Basecourse
3	Steel grid
4	Geotextile
5	Excavation limit

Figure 6.2 The Standard Rehabilitation Structure

When using steel grid reinforcement in the rehabilitation structure (and this is recommended), the weight of the steel grids must be included in the weight of the rehabilitation layers. Grid reinforcement over culverts, pipes or cables may cause problems for future maintenance operations and these should be omitted at these locations or carefully designed to prevent future problems.

Case B: 'The Lightweight Structure'

An alternative replacement road structure, using lightweight fill material, can also be considered if there is a suitable and economic source of lightweight material available locally. Table 6.1 below lists a range of the more commonly used lightweight materials in road construction.

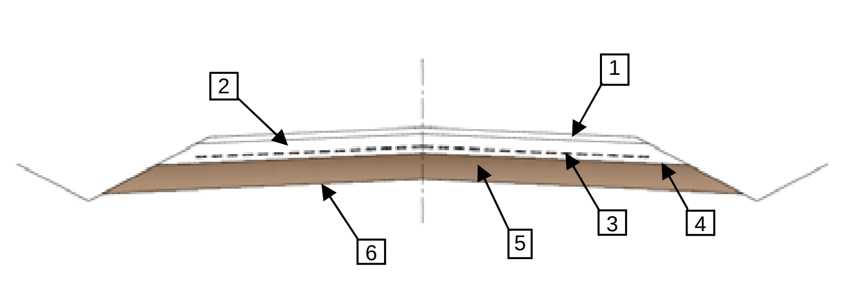
Table 6.1 Typical lightweight fill materials.

Material	Dry Density kg/m³	Bulk Density kg/m³	Comments
Lightweight Expanded Clay Aggregate	300-900	650-1200	Manufactured product. Lightweight aggregate produced by heat expansion of clay pellets. Range of densities due to water absorption. Normally requires 0.6m of road construction above. May be difficult to compact if unconfined.
Pulverised Fuel Ash	700-1400	1300-1700	By-product of coal fired power stations. Naturally cementitious, especially useful in backfills to bridge abutments.
Slag	1000-1400	1400-1800	By-products of steel industry. Generally at the 'heavy' end of lightweight materials. Leachates can be an environmental problem.
Aerated slag	500-1000	1100-1700	Foamed by-product formed by quickly quenching molten slag in water.
Volcanic ash	650-1000	1400-1700	Natural material (particularly useful in Iceland).
Bark/woodchip	100-300	800-1000	Aged bark can have good properties for road construction and be beneficially used but can give leachate problems in sensitive environments.
Expanded Polystyrene	20	100 for design	Manufactured product. Extremely light, generally produced in blocks, relatively expensive, 100kPa minimum compressive strength. Installations are usually capped with a concrete slab. Requires protection from petrol, fire and UV light.
Foamed concrete	600-1800	1000-1800	Manufactured product. Pre-foam added on site to ready-mixed mortar, 4MPa minimum compressive strength
Compressed peat bales	200	600-800	Past installations still exhibiting 20% buoyancy after 10 years submergence, not generally available.
Foamed glass	100-500	100-500	A new product manufactured from waste cathode ray tubes, stable, inert material, compressive strength 6-12 MPa.
Waste tyres Bales	500-650	500-650	Waste tyres compressed into bales and bound with galvanized wires.

In road rehabilitation works these lightweight materials are used primarily to reduce the overall weight of the road and so reduce the loading on the peat. A typical lightweight structure, based on the standard rehabilitation structure, is given below.

B - LIGHTWEIGHT REHABILITATION STRUCTURE
1. removal of old wearing course 2. removal of old material (this depth will be determined by the need to be able to replace sufficient existing heavy material with lightweight material to produce a lighter replacement road structure) 3. installation of a geotextile separator 4. new lightweight fill material 5. covering of a geotextile separator 6. provision of new base course material 100 mm 7. installation of new steel reinforcement 8. new base course material 200 mm 9. new wearing course 100 mm (or a new flexible pavement layers for a paved road)

When used appropriately, this type of lightweight solution can restore the road profile to its former level without adding weight to the road and, where circumstances permit, allow the grade line to be raised above a drainage or infrastructure problem. The lightweight material in the new structure should be enclosed by a suitable grade geotextile separator selected to suit the lightweight fill and strong enough to resist punching by the base course material aggregate.



No	Layer
1	Wearing course
2	Basecourse
3	Steel grid
4	Geotextile
5	LW material
6	Geotextile

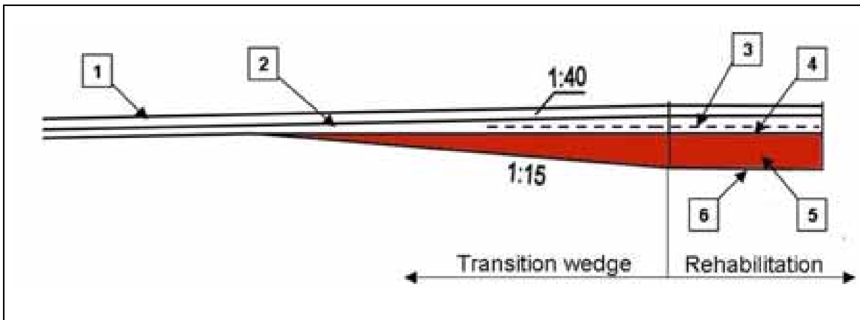
Figure 6.3 Lightweight rehabilitation structure

It is recommended that a minimum of 400mm of road construction material is placed on top of the lightweight material as a structural layer. This depth of layer also provides a heat storage mass to counter any variation in icing conditions along the finished carriageway between sections of normal road construction and lightweight fill. This is a major consideration in areas with long cold winters.

The Transition Wedge

The transition zone, for the purposes of this report, is the changeover from a sound subgrade to a peat subgrade. This happens where the road crosses on to peat and where it leaves the peat. These areas regularly cause problems if not treated correctly and the key to an effective solution lies in the creation of an engineered transition between the 'hard' and the 'soft' that will allow the road to adapt to the change in bearing circumstances without undue settlement and cracking.

For this to happen a 'transition wedge' must be constructed in the sound material and have reached full depth before the rehabilitation on the peat. If it is constructed on the peat it will fail. A typical transition wedge is shown below:



No	Layer
1	Wearing course
2	Basecourse
3	Steel grid
4	Geotextile
5	LW material
6	Geotextile

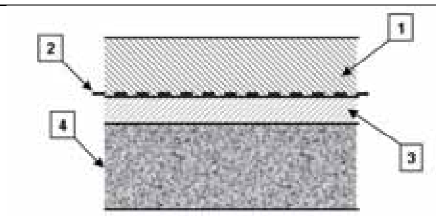
Figure 6.4 Longitudinal section through a transition wedge

The lightweight material transition length should be constructed to a slope of 1:15 and the base course to a slope of 1:40. (Aho & Saarenketo, 2006, "Design and Repair of Roads Suffering Spring Thaw Weakening")

Case A1: 'Reinforced overlays of paved roads'

As mentioned earlier in section 6.2.1 it is possible to use reinforced overlays as rehabilitation solutions for deformed and cracked paved roads where the settlement of the carriageway is not a major consideration. Such reinforced overlays have been used with good results on rural low volume roads in the Scottish Highlands both with polyester grids and twisted steel mesh. The basic structure for these installations is shown below:

A1 REINFORCED OVERLAYS FOR PAVED ROADS
1. reshape deformed carriageway with bituminous material 2. fix new grid. Polyester grids require the surface to be sprayed with an adhesion agent. Steel meshes require to be nailed down. 3. new bituminous wearing course 50-60 mm



No	Layer
1	Wearing course
2	Renforcement
3	Regulating layer
4	Existing pavement

Figure 6.5 Reinforced overlay for a paved road

This structure does however incur settlement as it adds loads to an existing floating embankment and this should not be underestimated when planning rehabilitation works using this technique. The effects of a Maccaferri 'Roadmesh' double twisted wire mesh steel reinforcement on road performance can be seen in the 'Road Doctor' screen shown in Figure 6.6 below.

If the existing bituminous layers are thick enough to allow milling it is possible to carry out this exercise within the weight of the existing road as recommended. In this circumstance the process is as follows:

A1 REINFORCED REPLACEMENT FOR PAVED ROADS
1. mill off 100mm of existing bituminous pavement 2. fix new grid. Polyester grids require the surface to be sprayed with an adhesion agent. Steel meshes require to be nailed down. 3. new bituminous wearing course 50-60 mm

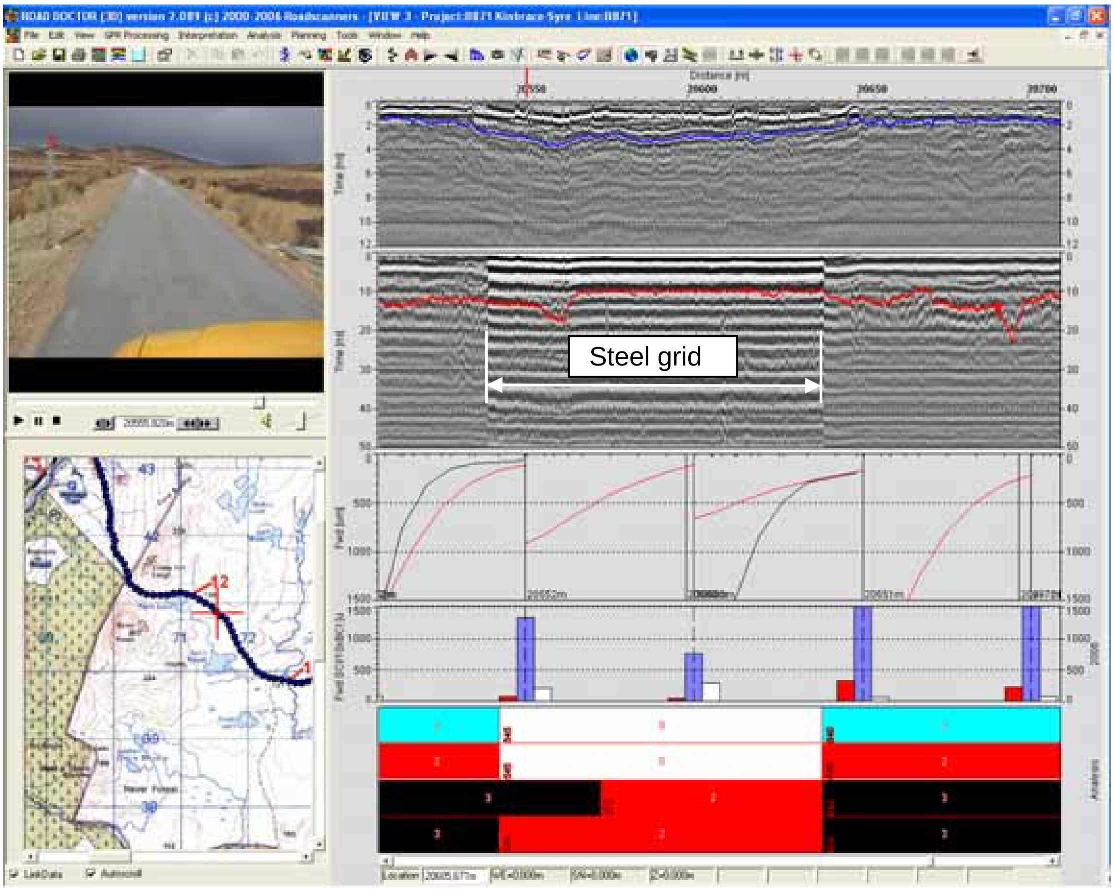


Figure 6.6 Road Doctor integrated analysis screen from the B871 public road, Scotland.

This screen shows the results of a steel reinforced overlay on a single track paved road in northern Scotland. The steel reinforced section extends from 20540 to 20640 and can be seen in the GPR plot as a strong noise blurry area. The improvement in pavement performance can be seen in the plots of the FWD taken before the project (black lines) and with the steel grid (red lines). The steel grid used was a Maccaferri twisted steel "Roadmesh".

6.2.2 Embankment settlement

Embankment settlement over peat covers a wide range of issues and consequences, not all of which can be addressed in this simple rehabilitation summary. An introduction to the bearing capacity, stability and settlement, of embankments over peat is given in the ROADEX II report "Dealing with bearing capacity problems on low volume roads constructed on peat" (Munro 2005) and readers are referred there for background.

This report will consider the typical road rehabilitation problem of a floating road embankment settling into peat, with possible flooding of the carriageway, and deal with the problem using the general principle of 'causing no further harm'.

Case C: The Lightweight Embankment Replacement

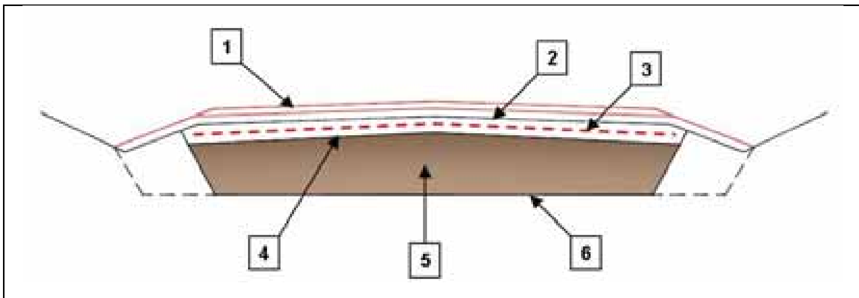
The sequence of construction operations on site for the rehabilitation of a floating embankment over peat generally follows that of Case B, the lightweight fill rehabilitation of a carriageway, but with greater awareness of the need to protect the existing established water table and hydrostatic uplift effects on the embankment. These hydrostatic forces are essential to preserve the established equilibrium in the peat and every effort should be made to understand the implications of the changes being proposed and their effects on the permanent works.

The rehabilitation sequence as before is:

C - LIGHTWEIGHT EMBANKMENT REPLACEMENT
1. removal of old wearing course 2. removal of old road construction layers 3. removal of old floating embankment (this depth will be determined by the need to be able to replace sufficient existing heavy material with lightweight material to produce a lighter replacement embankment) 4. geotextile, filter grade 5. replacement lightweight material 6. geotextile, filter grade 7. base course material 100 mm 8. steel reinforcement 9. base course material 200 mm 10. wearing course 100 mm (or a new flexible pavement layers for a paved road)

In this case it is generally necessary to remove the whole old road embankment completely to maximize the potential for ‘offloading’ the peat. If the offload ratio of the weight of the old embankment to the weight of the new embankment can be 2 or more the resulting rehabilitated road should be free of significant settlement in the medium to long term.

A typical structure using lightweight material is shown below:



No	Layer
1	Wearing course
2	Basecourse
3	Steel grid
4	Geotextlle
5	Basecourse
6	Geotextile

Figure 6.7 Rehabilitation of a road embankment with lightweight material

The transferability of rehabilitation practices, and the benefits of sharing technologies, across the Northern Periphery can be seen in 2 similar projects from

Finland and Scotland that ‘offloaded’ existing road embankments using lightweight material. Although separated geographically by 2,000 km, as well as different cultures, languages and currencies, the 2 projects produced successful solutions for common problems.

Figure 6.8
Lightweight rehabilitation project in Finland

Figure 6.9
Lightweight rehabilitation project in Scotland

Further details of the projects, and others using different types of lightweight material, are given in the ROADEX II report “Dealing with bearing capacity problems on low volume roads constructed on peat” (Munro 2005).

This solution can also be used to raise a road embankment provided that a sufficient depth of heavy material can be removed from the existing road construction to allow for the increase in height with lightweight material. The ‘super lightweight’ properties of expanded polystyrene, EPS, can be very useful in this case and a number of case histories of the use of EPS are given in Munro (2005).

6.2.3 Widening of a road

The widening of a road founded on sound ground is generally a relatively easy exercise achieved by first widening the existing road embankment and then constructing the widened carriageway on top. A similar exercise can also be done on a road embankment over peat by excavating out the adjacent peat and building the new widening on the exposed firm layer. This however can be an expensive practice especially with ‘floating roads’ over deep peat and it can also pose real problems if the new widening areas act as linear drains to dewater the peat below the existing road causing settlement, consolidation and deformation.

A cheaper solution and less harmful solution for widening ‘floating’ low volume roads over peat is by using preloading. This method can be a cost effective solution where the existing road construction is considered to have become stable enough over its lifetime to permit its retention in the new works. In these circumstances preloading, aided by a surcharge, can be used to bring the adjacent bog up to a strength equal to that of the peat below the road, at which time the new widened road can be constructed on the common embankment. More information on this type of preloading is given in the ROADEX II report “Dealing with bearing capacity problems on low volume roads constructed on peat” (Munro 2005).

A typical road widening project using the preloading principle, as carried out by The Swedish Road Administration, is given below:

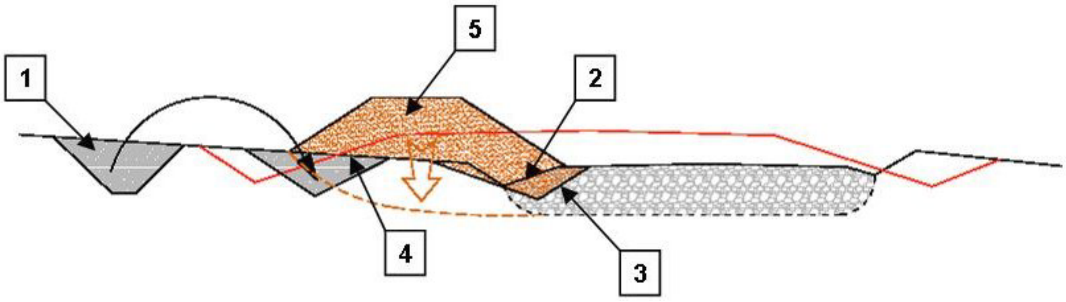


Fig 6.10 Widening using preloading (Lars-Göran Svenssen, Swedish Road Administration)

The construction sequence for this type of widening is given table D below. .

D - FLOATING ROAD WIDENING
1. dig new intercepting ditch 10m off the old road and use excavated peat to refill the existing roadside ditch
2. remove fine materials from the road shoulders, approx 200mm deep
3. lay separator grade geotextile on prepared shoulder and reform with good material
4. lay 5m wide reinforcement grade geotextile below area to be preloaded
5. commence preloading of the road widening in 1m stages until the designed preloading height is reached
6. leave preload in place for 90 days and monitor performance by means of settlement plates (see Figure 7.2)
7. remove excess preload material after the designed settlement has been achieved
8. construct widened road as set out in rehabilitation structure A

The design process for this type of widening needs a geotechnical input to estimate the height and duration of the preloading required together with the predicted likely settlement to be incurred but this should not deter non-geotechnical engineers provided that this advice can be obtained.

This form of widening can usually be carried out without affecting traffic flows on the existing road as can be seen from the site photograph in Figure 6.11. A more detailed account of the method, with further references, is available in Munro (2005)

Fig 6.11 Photograph of a widening of a floating road over peat by preloading.

The road widening example shown by red line in figure 6.10 illustrates a higher, and therefore heavier, road that will cause a consolidation and settlement into the peat when the new carriageway construction is laid. This has been drawn above the existing road for ease of reference. It is not however necessary to raise the road for this technique to work. If the finished road is to be reconstructed to the same loading as the existing road weight, and this is preferable, the new road construction should be carried out in accordance with the guidance given in the standard Case A where the new carriageway replaces the existing.

Chapter 7. MONITORING & RECORDS

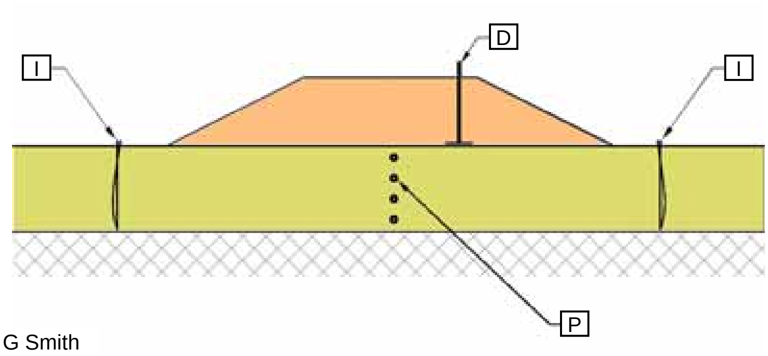
7.1 GENERAL

The monitoring of the performance of peat associated with rehabilitation works has a number of significant benefits.

- In the short term: if nothing else, a good system of monitoring can confirm that settlement and consolidation are going according to plan. This is an important check. A good system of monitoring can identify any departures from design early enough in the work so that appropriate action can be taken.
- In the medium term: monitoring can help identify the likely rate of post construction ‘secondary compression’ settlement of the road. If this rate is not in accordance with the design plan, again, modifications can be implemented to bring it into line.
- In the longer term: site monitoring records are vital to build up improved databases of local peat deposits and peat characteristics for use in future projects. Information from the current project, and any monitoring, should be added to these databases to increase the base of information for future projects.

7.2 MONITORING INSTRUMENTATION

A typical installation for monitoring is shown below:



“D” = settlement plate
“I” = inclinometer
“P” = piezometers

Figure 7.1. Typical instrumentation installation for an embankment on peatland.

Further details of typical monitoring installations are given in the ROADEX II report “Dealing with bearing capacity problems on low volume roads constructed on peat” (Munro 2005).

The most useful monitoring device for a floating road on peat is a ‘surface settlement plate’. This is a simple visual measuring device and normally consists of a flat plate (usually 500mm x 500mm) on to which is welded a rod of sufficient length to ensure that the end continues to be exposed to view once the settlement has taken place. The plate is positioned on the surface to be monitored, such as a construction layer, a geotextile layer or an original ground surface and a record taken of the level of the exposed end as the settlement happens. As an added sophistication the rod can be sheathed in a duct to protect it during settlement of the overlying fill. These plates are then referenced back to fixed ground control points for consistency of monitoring.

Figure 7.2 Surface settlement plate

Chapter 8. CONCLUDING REMARKS

The rehabilitation of floating roads over peat is a common problem in road engineering across the European northern periphery, especially on the low volume road networks of the rural areas. Here, limited road maintenance budgets increasingly require local engineers to deliver more cost effective solutions in an effort to keep their local networks fit for the demands of modern heavy haulage traffic.

This guidance document aims to help this situation by setting out best practice procedures for rehabilitating roads over peat using well working experiences taken from across the ROADEX Partner areas. The proposed 'ROADEX method' takes the form of 5 steps:

1. identifying the underlying problems through appropriate surveys
2. analysing the information collected
3. selecting the most suitable rehabilitation measures
4. monitoring the work during construction
5. recording and sharing the results

Step 1 in this method is never a wasted effort. A small expenditure of money expended in the preliminary investigatory works can give great returns in real knowledge as to how a particular peat deposit was formed, its insitu characteristics and engineering properties as well as the history of its consolidation under the weight of the existing road. This information is particularly important if appropriate and 'fit for purpose' solutions, suited to the particular road section, are to be found.

In step 2 the method of 'integrated analysis' described within the report provides a practical mechanism for analysing collected data in one place, on one screen, to facilitate the analysis and design process. This method has been used extensively across the ROADEX districts over a number of years and good quality results.

A central principle of the method is the need to preserve the established system of equilibrium that has built up between the existing road and underlying peat over time. This road/peat equilibrium is a real strength of the floating road method and must be protected during the works to ensure that the existing balance of forces is not lost.

Finally, all rehabilitation works involving peat should be recorded for future use and reference. The engineer faced with a rehabilitation problem over peat should always look to past records to learn from. Assuming that this is the case, that same engineer should also be prepared to add their record to the database of projects for future engineers to learn from.

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