Dealing with poor bearing capacity on low volume roads on peat in the Northern Periphery

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ABSTRACT: The Roadex II project is an EU funded trans-national technical co-operation between the northern European roads districts of Finland, Norway, Sweden and Scotland whose main aim is the sharing of technical information and good practice. The goal of sub-project 2_5, 'Dealing with Bearing Capacity Problems on Low Volume Roads Constructed on Peat' was to gather together existing and past practices for dealing with bearing capacity problems for roads constructed on peat in the Partner roads districts, with particular reference to lightly trafficked roads. As part of this exercise interviews were held with practising roads and geotechnical engineers in the Partner areas to gain as full an insight as possible into their current thinking. The result of the research is a snapshot of the Partner area practices in dealing with bearing capacity problems in roads constructed over peat that covers such topics as the classification and engineering properties of peat, local field survey methods, testing, design considerations, risk management, methods of construction supplemented by local case studies. This paper gives a summary of the research carried out within the Partner areas and offers a 'snapshot in time' of local thinking for dealing with bearing capacity problems on low volume roads constructed on peat.

KEY WORDS: Roads, peat, construction, Roadex, survey

1 INTRODUCTION

Road construction over peat presents great challenges to the intending road builder not only in the landscapes and terrains that have to be crossed but also in the management of the engineering properties of the peat, ie high water content, high compressibility and low strength. Faced with these engineering obstacles, coupled with the associated considerations of low bearing capacity and excessive settlement, the roads engineer has to develop careful designs to be able to construct a safe, stable and serviceable road.

Because of this road construction over peat tends to be a very 'conservative' science, particularly in the planning, design and construction of major public roads. Engineers dealing with these roads rightly shy clear of construction risk wherever possible and usually opt for the safer and conventional forms of construction whereby the peat is totally removed and replaced with sound road foundation material. This of course is an expensive solution and a primary user of scarce natural resources from local environments, and only really appropriate for the construction of national high speed roads.

For lower classes of road, an awareness of the "usability of peat" as an engineering foundation is more common, particularly in those geotechnical communities in countries with large peatland areas such as in the Northern Periphery of Europe, where the "green issues" associated with earthworks construction are increasingly important. For these reasons a growing number of geotechnical engineers are actively pursuing cost effective and innovative solutions for improving bearing capacities of minor rural roads over peatlands rather than ignoring the material out of hand. Through their efforts peat is no longer being dismissed as an engineering foundation.

2 PEATLANDS

The word 'peatland' can be simply defined as 'an area of land where peat is found' but this definition takes no account of the great range of types and descriptions used for 'peatland' across the world. This paper will use the terms 'peatlands', 'mires', 'fens' and 'bogs', as they are defined in the Irish Environment and Heritage Service "Peatlands" website www.peatlandsni.gov.uk. These are:

- Peatland - an area with a naturally accumulated peat layer at its surface
- Mire - a peatland where peat is currently forming and accumulating
- Fen - a peatland which receives its water and nutrients from the soil, rock and groundwater as well as from rain and/or snow
- Bog - a peatland which receives its water solely from rain and/or snow falling on its surface

2.1 Formation of Peat

'Peat' forms in a landscape when the natural vegetation decay processes fail to keep up with the amount of vegetable material being produced. This usually happens on waterlogged lands starved of oxygen where the lack of oxygen prevents the natural micro-organisms from decomposing the insitu plant material. Where this condition occurs the dying vegetation does not decay at the end of the growing season as would normal happen but instead the material accumulates year on year as a peat layer. Peat forms slowly in this way taking approximately 10 years for 1cm of peat to form. The most important feature in this building process is water and in particular the water balance within the peatland. For a peatland to survive, the water balance in the peatland cannot be negative, the water input into the area must be greater or equal to the water loss.

This paper will concentrate on those mires, fens and bogs formed by the processes above and will ignore organic soils where the organic material has been washed into place by inundation, flood, rivers, etc. These soils, generally with high mineral contents, will be considered to be outwith the classification of a peatland.

2.2 Morphology of Peat

Peatlands are normally classified according to their topographical and hydrological features, otherwise known as their 'morphology' and within the Northern Periphery three types of peatland morphology are common:

- fens (or 'aapa' mires in Finland)
- raised bogs, including blanket bogs
- palsa mires

and their distribution across the Northern Periphery can be shown in Figure 1 (Succow & Jeschte 1990).

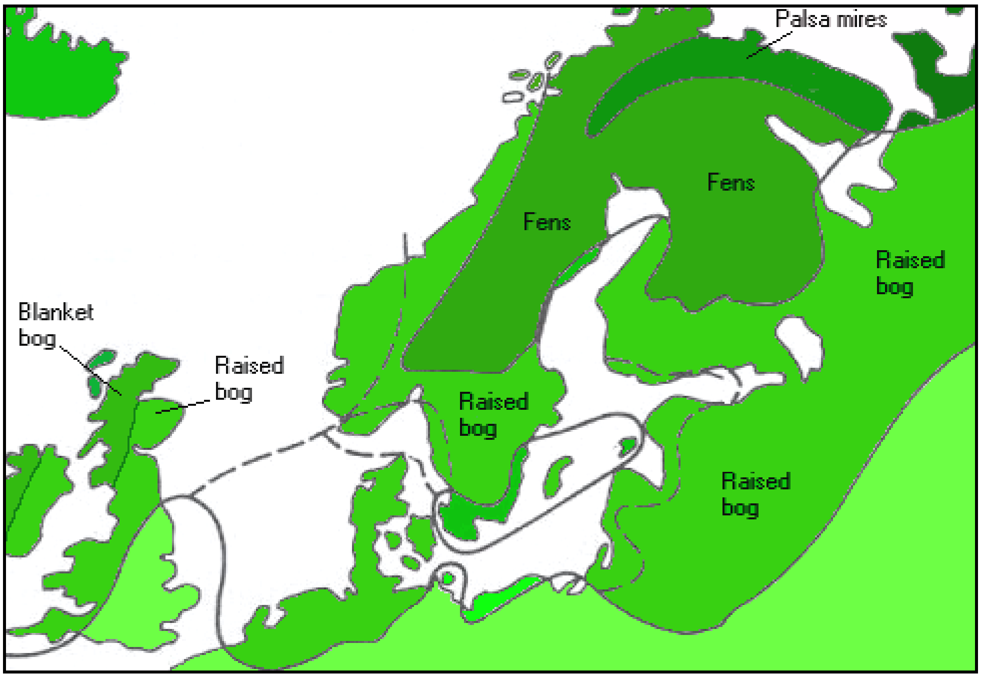


Figure 1: Distribution of mire zones across northern Europe based on Succow & Jeschte 1990.

2.3 Peat Characteristics and Properties

Peat can be a highly variable material and the engineering properties of a particular peat deposit are invariably a consequence of its formation and morphology. At one end of the scale fibrous peats will have a visible plant structure with little humification almost resembling a mat at times and at the other end of the scale amorphous peats will have a highly decayed structure with no vegetable fragments whatsoever, in many ways resembling a clay. This variability can be expected to occur throughout a deposit, both horizontally and vertically, again as a result of the peatland's morphology. Significant variation in peat type can happen within as little as 5-10 metres horizontally and even less vertically and great care has to be taken to select suitably representative areas for site sampling and testing.

Classification of peat samples can be carried out in a number of ways but the most popular in the Northern Periphery are the 'degree of humification' method (promoted by Von Post & Granlund, 1926) and the 'visible structure' method (promoted by Radforth 1969). In the Von Post method peat samples are squeezed by hand and the colour and consistency of the material that extrudes through the fingers is noted, as H1 to H10, to indicate the degree of decay of the plant material. The Radforth system in comparison relies on a visual description of the sample by categorizing the sample firstly into 3 basic types of 'amorphous-granular peat', 'coarse fibrous peat' and 'fine fibrous peat' and thereafter into 17 sub-categories.

Peats can be subject to many laboratory tests and a wide range of indicators and properties can be recorded. Of these probably the most important is water content, ranging from 500% to 2500%, as this parameter governs many of the engineering related properties of interest to the road builder. A good description of the extensive range of tests that can be carried out on peat is written by Hobbs (1986).

3 ENGINEERING CONSIDERATIONS

The selection of a method for the construction, improvement or rehabilitation of a road over peat will normally be based on a combination of economic considerations coupled with the performance requirements expected of the new carriageway. Most public roads, even relatively high speed roads, can stand fairly large settlements if they are long and even particularly where the ride quality is not significantly affected. Short differential settlements across the carriageway on the other hand can pose quite dramatic hazards to fast moving vehicles and these will usually require to be designed out if at all possible. High speed national networks as a consequence normally employ conservative methods to satisfy the tight carriageway tolerances involved. Lightly trafficked lower class roads on the other hand will usually be able to exploit the less expensive, less rigorous solutions available, particularly where vehicle speeds are likely to be lower. But irrespective of which end of the performance spectrum a particular road embankment lies it will have to be designed to meet the two main engineering criteria of embankment stability (bearing capacity) and settlement.

3.1 Stability, Bearing Capacity and Settlement

The terms 'bearing capacity' and 'peatlands' do not sit well together. Peat in its natural state is a balance of water and decomposing plant fragments with virtually no measurable bearing strength. It can be transformed however, under suitable circumstances and engineering methods, into an acceptable foundation material but its extensive range of morphologies and types does not permit a single indicator of 'peat bearing capacity' to be easily proposed. A broader description of bearing capacity for peat is therefore required

'Bearing capacity' in its classical soil mechanics sense can be defined as "the ability of a soil to safely carry the pressure placed on the soil from any engineering structure without undergoing a shear failure with accompanying large settlements' (U. S. Army Corps of Engineers, 1992). The same source defines 'ultimate bearing capacity' as the pressure to cause a 'critical plane of failure (slip path) in the soil'. In applying these definitions to peatlands therefore it seems prudent to consider 'shear failure', 'settlement' and 'critical planes of failure' in any discussion of bearing capacity over peat. The "Centre for Civil Engineering Research and Codes" of Indonesia and The Netherlands reports that the main problems in constructing roads over peat and organic soils are 'stability and long term settlements' and develop their "Guideline road construction over pear and organic soils" accordingly. Their guideline identifies settlement and shearing/stability as 2 of the main geotechnical mechanisms involved in road construction over peat soils. This view is also strengthened by the US Transportation Research Board, Transportation Earthworks Committee (AFS10) who welcomed research in 2004 for 'the stability (bearing capacity) of embankments'.

This paper will take this wider view of bearing capacity and for the purposes of this paper 'bearing capacity' will be taken in its broader sense and include the consideration of stability and settlement.

3.2 Bearing Capacity

All embankments need to be designed to be stable and constructed in such a fashion so as to produce a sufficient factor of safety against foundation and sideslope failure. This failure can be by failure of the underlying peat along a slip surface, normally in the form of an arc, or punching shear into the underlying peat where the embankment settlement is accompanied by heave of the adjacent peat bog alongside the embankment. Appropriate analyses should be carried out ahead of the construction works to ensure that these failure conditions are avoided.

Various forms of proprietary stability analyses are available on the geotechnical market and Internet such as PLAXIS, OASYS, FLAC, SAGE, etc and the selection of the most suitable method of analysis (spreadsheet, general analysis, finite difference/finite element analysis, 2 dimensional, 3 dimensional) should be left to an engineer experienced in the field. As part of this analysis it will be necessary to examine the short term construction stability of the embankment, including the effects of the different phases of the embankment construction, as well as the long term stability of the chosen method of construction. Embankment stability is unlikely to pose a design problem on fibrous bog peats however due to the reinforcing effect of the peat fibres but it can be a significant consideration in the design and performance of embankments over fen peats which tend to be more humified and less permeable.

3.3 Settlement and Consolidation

The settlement of an embankment on peat can be considered in 2 parts; magnitude and rate of settlement. The rate of settlement, and the time needed for the embankment to settle, is normally the more important consideration of the 2 parameters for a road related project if future post-construction maintenance is to be minimized. The early estimation of the magnitude and rate of settlement is therefore a significant factor in a successful embankment over peat.

Peat exhibits an immediate 'elastic' settlement as soon as it is loaded and a 'consolidation' settlement thereafter. It is possible to estimate the immediate settlement element but most authorities in the Northern Periphery choose to ignore this and concentrate their efforts in assessing the magnitude of the 'consolidation' settlement as this has a far greater effect on the serviceability of the finished road. An embankment on peat settles (consolidates) in 2 stages; the 'primary' consolidation stage as the pore water is squeezed out of the peat mass and the 'secondary compression' stage as the internal peat matrix slowly takes up an increasing share of the embankment load as it increases in strength. These phases can be estimated by a number of means but all methods currently produce only general predictions due to the variation in peat already discussed. Site instrumentation is considered essential to check that settlements on site are proceeding as predicted.

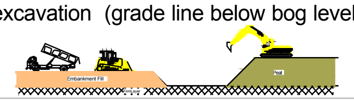
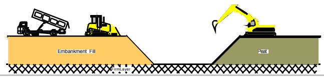
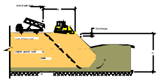
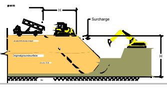
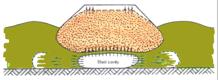
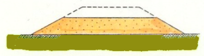
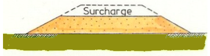
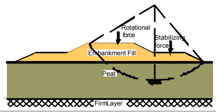
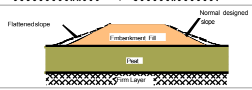
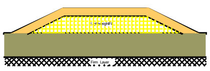
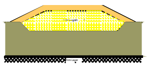
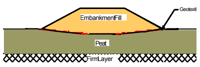
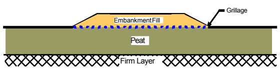
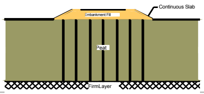
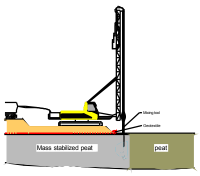
4 EXPERIENCES OF THE ROADEX PARTNERS

The author visited a range of Partner offices during the research project and all had the common practice of applying low risk, standard techniques, such as Peat Excavation, Replacement and Displacement, to the construction of main national routes, restricting the use of the less developed and more innovative techniques such as soil improvement, geosynthetics, etc, to the lower classes of regional and district roads. The proven 'left in place' techniques such as 'preloading' and 'surcharging' were only considered acceptable where there was sufficient time and flexibility in the construction period to allow the technique to produce the required improvement in strength.

The majority of the engineers approached during the course of the project were aware of the range of construction techniques available for roads over peat but most had their own preferences of 2 or 3 alternatives that they tended to use regularly. All of those questioned however indicated that they would be prepared to use the more innovative techniques where they could be shown to be appropriate or cost effective for their particular projects. The choice of technique for a particular location was generally determined through a combination of the cost influencing factors of the complexity of the particular engineering works, the amount of soils investigation and testing necessary for each method, the required time for execution of the method, the type of budgetary control in force (the rate of return, number of financial years, etc), the amount of traffic disruption and additional traffic control required by the works, the expected future maintenance liability and it was only after all of these construction and maintenance effects were examined that the most cost effective solutions emerged and final choice was made. Within this philosophy the use of construction practices over peatlands in the 4 Roadex partner districts can be summarized as below:

- 'Excavation' and 'Replacement' are considered to be the most reliable methods particularly for major roads;
- 'Displacement' and 'Partial Excavation' continue to be used where appropriate but their use is declining as newer methods prove more economic;
- 'Peat left in place' techniques are used where Excavation and Replacement are considered too expensive and the Displacement technique is considered impracticable;
- 'Preloading' is the accepted technique for the improvement of bearing capacity of peaty subgrades and is normally carried out by Stage Construction to allow time for the subsoil to gain strength before the next layer is placed. Stage layers are generally 0.5m thick;
- 'Surcharge' is reckoned to be the simplest and most cost-effective method for accelerating consolidation in peat once the embankment has reached designed height. Typical surcharge amounts for peaty soils range from 0.1 to 0.2 times the height of embankment;
- 'Vertical Drainage' is not generally used on peat unless the deposit is seen to be contaminated or layered with less permeable soils such that it would benefit from the reduction in drainage paths;
- 'Stability' of embankments is occasionally enhanced by widening the embankment base by means of berms or slope reduction to produce a more deep seated potential slip surface;
- 'Piling' is considered to be too expensive for use as an everyday engineering solution for peat and is only used where settlement control is considered to be critical, eg on the approaches to bridge abutments;
- 'Geosynthetic' applications in road construction over peat continue to increase in the Partner areas especially in the maintenance and improvement of existing roads over peat. The special case of high strength geosynthetic reinforcement in basal embankment reinforcement is considered to have too many inherent risks for national strategic routes and is not recommended for these roads;
- 'Offloading' is considered to be a useful maintenance technique where a minimum of 50% of the existing weight of the road can be removed;
- 'Lightweight fills' are being increasingly used to reduce problems of embankment instability and settlement. The technique is thought to be at its best when used in conjunction with a heavyweight surcharge or in an offloading scheme where the removal of the heavier material can be expected to have a proportionately greater effect on the lightweight material below;
- 'Rafting' continues to have a role to play in construction over peat especially as a quick solution to bearing capacity problems. Timber and concrete rafts are decreasing in popularity due to high labour inputs but preformed steel rafts can be cost effective;
- 'Steel meshes' in road construction layers can often offer a shallow rehabilitation solution to low bearing capacity problems and are becoming increasing popular;
- 'Mass stabilisation' has moved on from being a research technology to having cost effective applications in mainstream engineering.

Table 1 Summary of Construction Techniques employed across the ROADEX Partner areas.

Technique	**Norway**	**Finland**	**Sweden**	**Scotland**
Peat excavation (grade line below bog level) 	Used regularly	Used regularly	Used regularly	Used regularly
Peat replacement (grade line above bog level) 	Used regularly	Used regularly	Used regularly	Used regularly
Progressive displacement 	Used Occasionally	Used Occasionally	Used Occasionally	Used Occasionally
Partial excavation 	Used Occasionally	Used Occasionally	Used Occasionally	Used Occasionally
Assisted displacement 	Used Occasionally	Not used	Used in the past	Used in the past
Preloading 	Used Occasionally	Used Occasionally	Used Occasionally	Used Occasionally
Surcharge 	Used Occasionally	Used Occasionally	Used Occasionally	Used Occasionally
Stage construction	Used Occasionally	Used Occasionally	Used Occasionally	Used Occasionally
Pressure berms 	Used Occasionally	Used Occasionally	Used Occasionally	Used Occasionally
Slope reduction 	Used regularly	Used Occasionally	Used Occasionally	Used Occasionally
Lightweight Fill 	Used Occasionally	Used Occasionally	Used Occasionally	Used Occasionally
Offloading 	Used Occasionally	Used Occasionally	Used Occasionally	Used Occasionally
Geotextiles & Geogrids 	Used regularly	Used regularly	Used Occasionally	Used Occasionally
Vertical Drainage	Not used	Not used	Used Occasionally	Not used
Timber rafting 	Used Occasionally	Used Occasionally	Used Occasionally	Used in the past
Piling 	Used regularly	Used regularly	Used Occasionally	Used Occasionally
Mass stabilisation 	Not used	Used Occasionally	Used Occasionally	Not used

5 MINIMUM RECOMMENDED PRACTICES FOR LOW VOLUME ROADS

The following practices are considered to be a minimum for low volume roads over peat:

5.1 Ground investigations & laboratory tests

- A desk study, any records of similar works constructed locally in the past;
- A site visit and 'walkover' to obtain a clear picture of the surface features of the peatland;
- A probing exercise to establish peat depths and any layering. This can be followed up by physical exploration measures if considered necessary that are suitable for the particular works (trial pits, Swedish sampler, DCP, GPR)
- Classification and degree of humification of representative peat samples;
- Water content tests for use in estimation of settlement.

5.2 Risk Management

- A simple risk register, kept up to date.

5.3 Monitoring

- Site records made and retained. (This is a direct plea from the author. Many innovative projects are being trialled with peat as a subgrade but without records being made. Any record is useful to future engineers, structured records are better.)
- Use of settlement plates and/or hose gauges.

6 GOOD PRACTICE IN THE ROADEX AREA - THE AUTHOR'S VIEW

39 examples of road construction and rehabilitation projects ranging in date from 1927 to 2004 are reported in the final report of the ROADEX II sub-project 2_5 (Munro 2005). These schemes are not specifically tailored examples of particular techniques but local solutions designed and constructed to meet local conditions. Techniques reviewed ranged from the use of expanded polystyrene blocks and geosynthetics in Norway, displacement and lightweight fills in Finland, preloading and mass stabilization in Sweden, and rafting and offloading in Scotland. Two techniques that particularly appealed to the author for simplicity and elegance are summarized below in illustration of good practice in the Northern Periphery.

6.1 Widening of Road No 867, Bäck to Yaböke, Hallands County, Sweden

This road was a 4.5m wide gravel road prior to widening in 1988. Part of the route crossed a 450m wide peat bog of up to 6m deep at Öxnalt. Georadar surveys established that the existing road had an overall construction depth of between 0.5 and 1.2m thick and that the old road had over its lifetime become stable enough to permit its retention in the new works. Preloading (and surcharge) was used to bring the adjacent bog up to a strength equal to the peat below the road and a new widened road constructed on the common embankment. It was calculated that preloading would be required for approximately 90 days.

A new intercepting ditch was excavated in the bog approximately 10m off the edge of the existing road on the side to be widened and the excavated material from it used to refill the existing roadside ditch. The shoulder of the existing road to be widened was graded to a depth of 200mm to remove the top poor fine surface materials before replacing them with a separating geotextile covered with 300mm of good granular material compacted to falls. A

5m wide reinforcement grade geotextile was laid on the existing shoulder, side slope and across the adjacent bog surface in readiness for the preloading embankment.

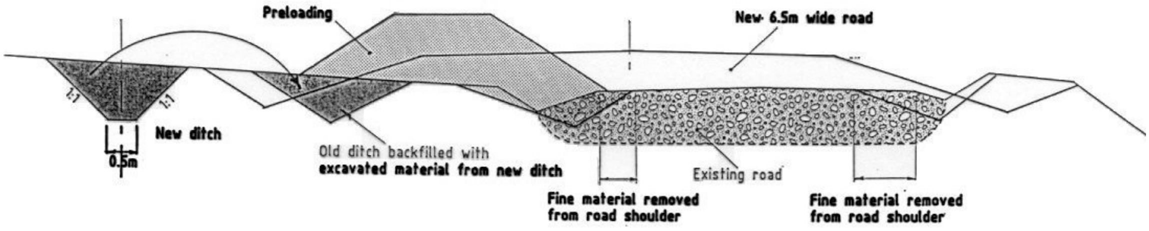


Figure 2: Cross-section through widened embankment. Source: P Carlsten, SGI and L G Svensson, Swedish National Road Adminstration, 1990

Preloading operations were commenced from the existing road by means of a 360º excavator placing the first layer of 0.5m of fill on to the geotextile. Subsequent layers were carefully controlled through the use of marked settlement rods that enabled the direct measurement of the actual preloading embankment depth to be known as settlement developed. The preloading heights varied from 1.0m to 2.0m depending on the depth of underlying peat. The sections of higher preload were placed in 2 staged operations 14 days apart. Settlement happened quickly. Up to 0.8m of settlement was recorded in the first few days of loading. The preloading was left in place for its designed period of 90 days without effect on the continuing traffic flows on the adjacent road. Over this period settlements were monitored and found to be generally in accordance with the design expectations.

On completion of the exercise the excess preloading material was dozed from the side on to the existing road to act as an additional roadbase layer. The road has since been paved and is performing well.

6.2 Offloading of Road No 280, Forssa to Somero, at Torrensuo, Finland

This road had a history of regular floods during times of high water levels that resulted in numerous road closures. In 1987 it was decided to replace the road in-situ with a higher and lighter embankment to lift the road out of the areas subject to flooding. Geotechnical surveys identified that the existing road lay on approximately 6m-8m of peat above a deep clay deposit. The strength of the in-situ peat varied from 4 to 8kN/m² (4 to 8kPa). The existing shallow gravel embankment was founded on an old timber grillage.

The road replacement design solution proposed removing the heavy gravel construction of the existing road and unloading the underlying peat by means of a LECA lightweight fill enclosed in a geotextile. Where additional bending stiffness was required a timber grillage was installed. Above this a new carriageway was constructed incorporating a structural steel mesh.

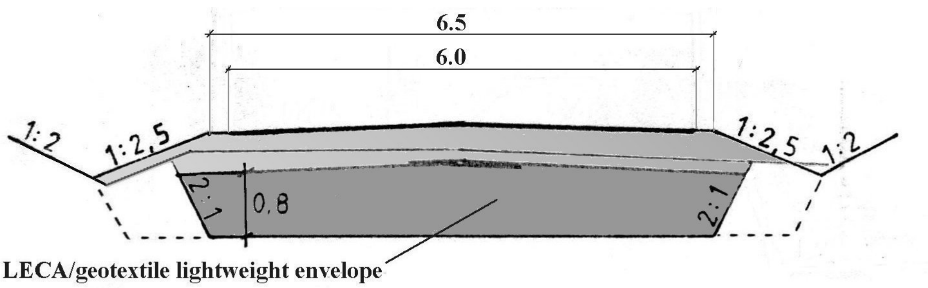


Figure 3: Cross-section through offloaded road. Source: A Valkeisemäki, Finnra, 2003

An interesting feature of the project was that the works were deliberately constructed in winter whilst the peat was frozen. The local hydrology, flooding problems and the presence of the National Park prevented the road being constructed in summer. The reconstructed road has been performing well since re-opening in 1987. Some minor uneven settlement was observed during a post construction monitoring survey in 2002 but this has not affected the trafficability of the carriageway.

The offloading technology was successfully transferred to the Scottish Highlands the following year.

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