Frank MacCulloch

GUIDELINES FOR THE RISK MANAGEMENT OF PEAT SLIPS ON THE CONSTRUCTION OF LOW VOLUME/LOW COST ROADS OVER PEAT

GUIDELINES FOR THE RISK MANAGEMENT OF PEAT SLIPS ON THE CONSTRUCTION OF LOW VOLUME/LOW COST ROADS OVER PEAT

January 2006
Frank MacCulloch
Forestry Civil Engineering
Forestry Commission, Scotland

The author would like to express his gratitude to Ron Munro of Munroconsult Ltd, David Killer and Iain Hampson from Forestry Civil Engineering and Colin MacKenzie, Consultant for their help and support in this project. Their assistance is greatly appreciated. The author would also like to thank the ROADEX II and III Project Partners and the Project Steering Committee for including this paper on the ROADEX website.

Contents

Appendices:

1. INTRODUCTION

There is an increasing demand from windfarm developers, the Scottish Executive and Local Authorities for guidance on how to assess the risk of peat slips associated with windfarm access roads. Forestry Civil Engineering (FCE), a part of the Forestry Commission, has been approached to provide this guidance. This report proposes a simplified methodology for the initial site assessment and provides guidelines to minimise the risk of peat slips during construction of the road.

1.1 Background

Peat slide risk has come to the fore as a consequence of the 2003 peat slide within the windfarm development at Derrybrien, Co Mayo, Ireland. This slide occurred in the Slieve Aughty Mountains of Galway on 16 October 2003 during excavations for the windfarm access roads.

At the time of the initial slide, ground movements appear to have been relatively minor but further torrential rain on 22 and 23 October triggered a second stage surge that escalated into a massive peat slide. This slide damaged two bridges, obstructed two roads, and polluted a range of watercourses (Fleming 2003 a & b). The Shannon Regional Fisheries Board conjecture that over 100,000 fish were in these watercourses at the time of the slip and estimate that over 50% of them died. It was subsequently alleged that construction activities at the Derrybrien windfarm contributed to the slide. As a result of this, the windfarm developer carried out a number of investigations into the circumstances surrounding the event. Reports of these investigations have yet to be published.

As a result of the Derrybrien incident, windfarm developers in Scotland are now required to give consideration to the likely risks of peat slides on developments involving peatlands, and on how any risk identified will be managed in the Works. This onerous requirement presents difficulties to potential developers as there is little factual information or guidance generally available to permit this to be done without incurring considerable costs. Having incurred that cost, there remains a risk that the development may subsequently be refused planning consent for completely unrelated reasons.

It is not in the interests of developers to be too prescriptive in detailing construction method statements in the early planning stages. This can stifle innovation in the later construction process ultimately leading to higher costs for the development and eventual consumer. However politicians, planners and land managers need to have some guidance on how to assess the information supplied by developers in the scoping appraisal as well as for the subsequent approval of the construction method statement.

In 1999 the government’s Construction Task Force looked at the UK construction industry and asked industry and government to join with major clients to create more innovative ways forward (Clayton 2001). The civil engineering sectors of the forest industry in Eire and the UK are fully supportive of this change, particularly in upland forest areas, as innovation is constantly needed to maximise the economic return from the low value timber resources. The windfarm industry has recognised this innovation culture and is increasingly using the technology developed by the forest industry to construct their access roads. These roads have to be capable of carrying heavy individual loads during the initial construction phases but thereafter revert to very low traffic volumes.

Road construction within a peatland constitutes a major challenge to the designer and contractor. As the characteristics of peat can differ enormously across a deposit, and even within a few metres, few definitive rules exist to assist the engineer. This variability makes the construction of a risk free, low volume/low cost road within a peatland, unrealistic. All involved with the construction of roads over peat must be aware that failure is to be expected and a process must be in place to minimise and manage the impact of any such failure.

1.2 Planning Process: Critical Path

Scotland usually generates sufficient power for its own needs. Any spare capacity goes to England and Wales. However, the present National Grid infrastructure for transferring this power south is approaching full capacity and considerable upgrade of the system is required to meet the new flows. This issue is now critical for developers with all vying for connection and trying to bring their scheme to fruition as soon as possible.

If a developer can obtain an agreed connection date to the Grid, regardless of planning consent, he then has a critical path for completion. Once on this path, the developer has to press both Local Authorities and Scottish Executive for consent, perhaps stretching the resources of those organisations. Any consequent delays will lead to a shortening of the residual available time for construction. These same developers also have shareholders who require a return on their investment. They also expect that once a development commences, the construction period on site will be swift irrespective of the ground conditions. This shortening of the available period for construction hat can have catastrophic effects when building roads within a peatland area.

2. TERMINOLOGY AND DEFINITIONS

2.1 Peat

Peat is a biogenic deposit which, when saturated, consists of about 90-95% water and about 5-10% solid material. The organic content of the solid fraction is very high, often up to 95% and is made up of the partly decomposed remains of vegetation that has accumulated in waterlogged areas over approximate timescales of 1metre in 1000 years. Over 90% of peat lands occur in the temperate or cold regions of the Northern Hemisphere (Maltby and Proctor 1996).

2.2 Mass Movement of Peat

"Slides", "bog bursts", "slips" are all terms used to describe unpredictable mass movements of peat. These are usually caused by weather events, but the exact failure mechanisms are not fully understood. Some factors that contribute to a peat slide can be identified. At present, gathering these contributing factors together to predict the position and timing of these slides, is not possible. However there is considerable difference between a natural event and a mass movement of peat caused by "human activities". The possible initiation of peat failure by these "human activities" requires to be managed in order to satisfy politicians and planners in order to allow development to proceed.

Throughout this report the following meanings are assumed:

Figure 1: Bog Burst

"Bog Bursts" occur due to the collapse or breakdown of the underlying drainage channels in an unconfined peat area, resulting in a saturated peat suddenly bursting onto the surface of the peat. The peat generally behaves as a viscous fluid and usually affects an area of less than one hectare (Tallis 2001). However, this small event can also trigger a larger "Slide" event

Figure 2: Peat Slide (reference no 27)

"Slides" occur in an unconfined peat area, as a result of a bog burst or as a natural event on side slopes. This generally occurs during a period of high rainfall following a period of dry weather. The most common theory is that during the "dry" period the water table falls, causing cracking and drying of the surface layer, subsequently allowing rainfall to penetrate into the peat matrix. This water ingress can then alter the peat strength, or lubricate a sliding surface within the peat. This results in a shallow translational failure, resulting in a slab movement of peat, with failure typically at or just above the peat/mineral interface. However there are other failure mechanisms and these are described in **3.1.2**. A large slide event can typically cover an area in excess of 50ha and an extreme event can involve the extrusion of five million m^3 (Tallis 2001).

Figure 3: Peat Slip.

- Slips" are failures of the peat as a result of the construction method. In the construction process the peat can fail in several ways;
  - By failure of the underlying peat along a slip surface.
  - By punching shear where the embankment settlement is accompanied by heave of the adjacent peat bog alongside the embankment.
  - During deposition of the peat spoil when porewater pressures are given insufficient time to dissipate.

2.3 Low Volume/ /Low Cost Road

The following terminology used in the report:

- A "low cost road" is a term from the forest industry now used in windfarm developments. It is used to describe a water bound road, generally built for a specific business purpose, with a cost per linear metre of less than 10% of an equivalent standard "A" class public road.

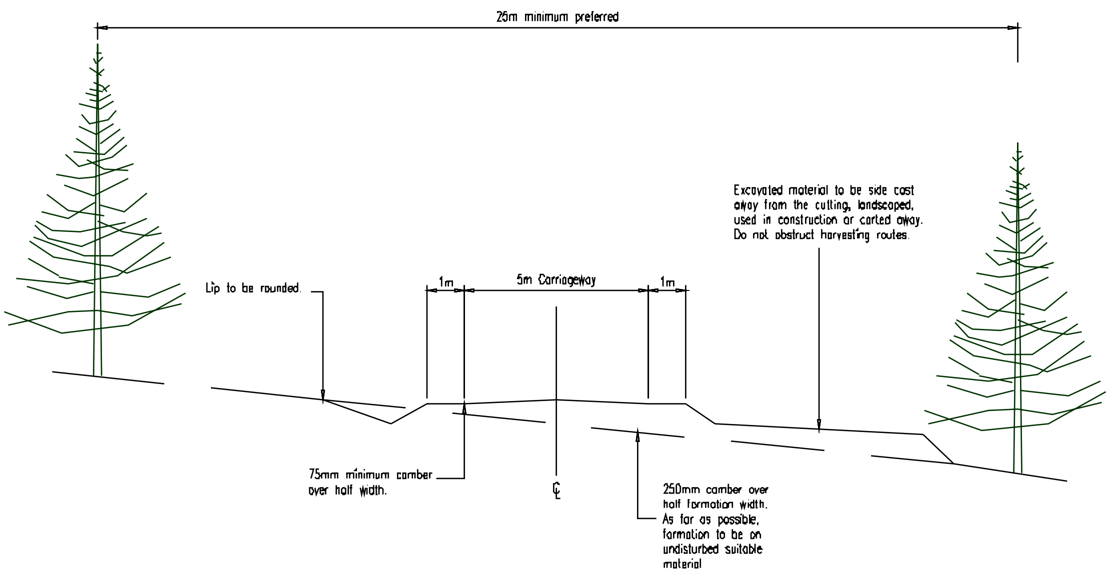


Figure 4: Typical Cross section for Windfarm access road

- A “low volume road” is the term used to describe a lightly trafficked road. This type of road will be subject to a very low number of standard axles over its lifetime, well below any standard design table for a public road. Typically these roads experience the highest traffic volumes during construction and revert to very low traffic volumes afterwards. This low volume loading with high axle weights poses interesting problems to transportation engineers in identifying suitable design methodologies and maintenance regimes for these roads.

Low Volume Road Type	**Indicative Daily Traffic Movements**
Northern Periphery Waterbound Public Road (for comparison)	<250 vehicles
Windfarm Road During Construction	100 vehicles
Windfarm road after construction	5 vehicles
Forest Road During Construction	30-40 vehicles
Forest Road During Harvesting Operation	Approximately 10

Table 1: Example of Traffic Volumes for Low Volume Roads

3. INCIDENCES OF MASS PEAT MOVEMENT

There are surprisingly few recorded incidents of peat movement in Scotland. Such records as exist are the larger “natural” incidents, usually resulting in blockage of a transport corridor. Some examples are Barra in the Western Isles in 1992, Morsgail also in the Western Isles in 1959 and Levenwick in the Shetland Islands in 2003. The author is also aware of several smaller incidents of localised slips due to construction activities on Forestry Commission ground and on private estates. These have not been recorded, as they tended to be small with little or no impact on the environment or traffic movements.

Peat slides have been recorded in Wales and in the English Pennines (Warburton 2004) but the majority of slides to date have been reported in Eire. Few so far have caused harm to people other than by affecting transport corridors or damaging buildings, but they can have significant effects on the surrounding environment, particularly water quality. Certainly the event in Derrybrien was an environmental disaster and is attributed to construction activities rather than a “natural event”. Reports suggest that, in upland peat areas it is estimated that the natural sediment yield in a watercourse can be 50 tonnes per km2. However in an extreme event 100 tonnes of peat per km^2 naturally enters a watercourse. (Wormon et al 2003).

3.1 Peat Slide Characteristics And Failure Mechanisms

When constructing a road in a peatland, the designer/contractor must understand both the common characteristics and failure mechanisms that can initiate a peat slide. This is essential to ensure the construction process does not trigger an event.

3.1.1 Common Characteristics

Sites of peat mass movement share the following characteristics that predispose them to failure:

- A peat layer overlying an impervious or very low permeability clay or mineral base;
- A convex slope or a slope with a break of slope at its head;
- Proximity to local drainage either from seepage, groundwater flow, flushes, pipes or streams; and
- Connectivity between surface drainage and the peat/impervious interface.

(Warburton et al 2004)

3.1.2 Failure Mechanisms

The following table compiled by Warburton et al (2004) brings together examples of failures, which have occurred in the UK and Eire. It is also describes the hydrological controls thus providing valuable information to any designer or contractor constructing a road within a peatland. Following the table are several pictorial diagrams of typical peat failures

Failure mechanism	Description	Hydrological control
Shear failure by loading	Hydrological loading- weight of absorbed water (rainfall, snowmelt) or snow	Absorption of water into the peat mass
	Increase in shear stress- hydrostatic pressure generated by water filled cracks ,ponds and lochs	Development of standing bodies of water in the peat
	Catastrophic loading – rapid increase in peat mass, exceedance of shear strength	"Hydraulic mining" by heavy localised "cloudbursts"
Buoyancy Effect	Generation of Artesian pressures	Routing of water to base of peat, (pipes, drains)
	Increase in interstitial pore-water pressure and reduction in cohesion	Transfer of surface water to base of peat through peat matrix.
Liquifaction	Basal peat slurried by increased water content (exceedance of liquid limit)	Routing of water to base via watercourses, infiltration, surface routing
	Basal Clay slurried by organic acid dispersal (passing of liquid limit)	Long term peat/clay interface chemical interaction
	General increase in basal moisture content by routing of artificial drainage	Down slope drainage impedance by blocked drains; enhanced upslope drainage by open drains and cuts
Surface Rupture	Swelling of basal peat leading to the rupture of the drier surface	Increase in water availability to basal peat
	Relative swelling of basal peat by contraction of surface during drought	Reduction in surface moisture content
	Long-term depth creep inducing surface rupture or shear failure.	Development of seepage pressures
Margin Rupture	Removal of underlying support by stream action –release of basal peat	External hydrological processes
	Removal of underlying support by peat cutting	Anthropogenic cause

Table 2: Examples of Peat failures and Hydrological Controls

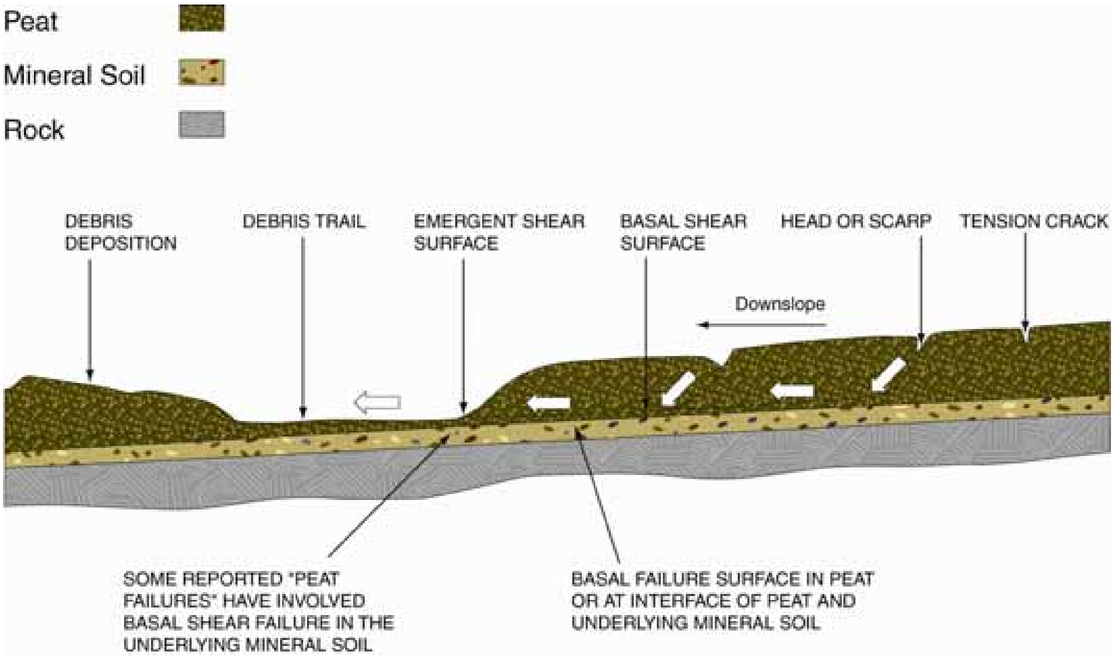


Figure 5: Typical definitions of peat failure

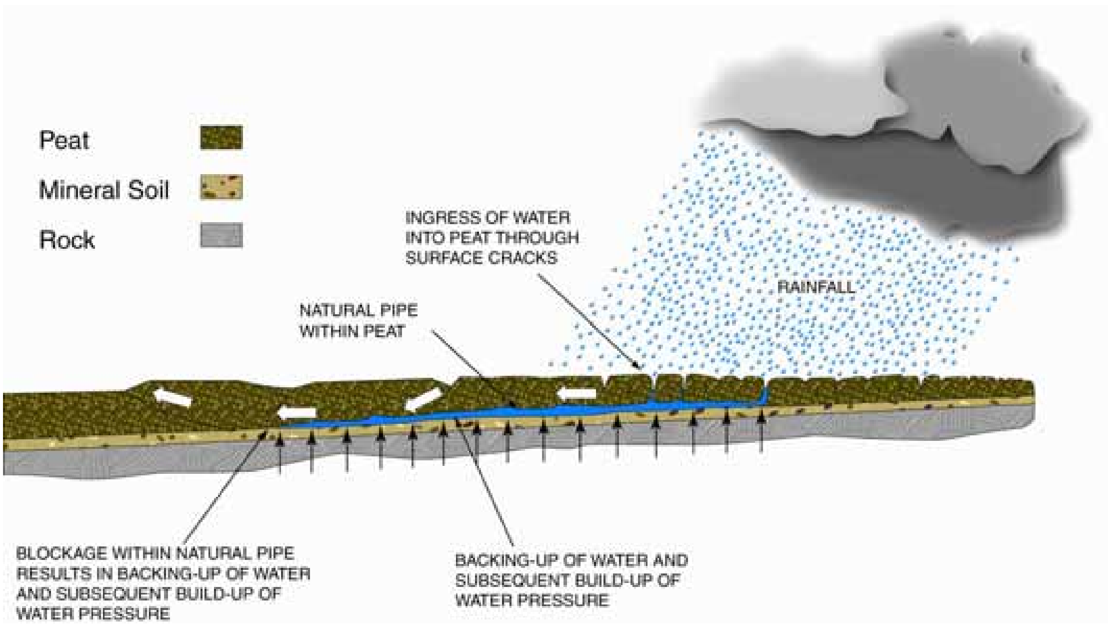


Figure 6: Typical water ingress through peat matrix

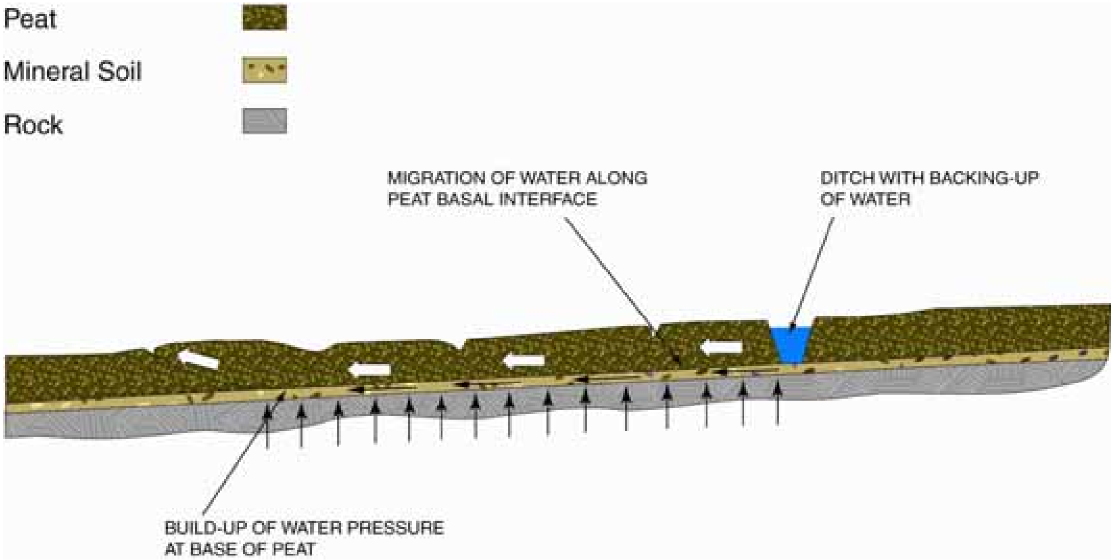


Figure 7: Typical failure due to blocked drainage

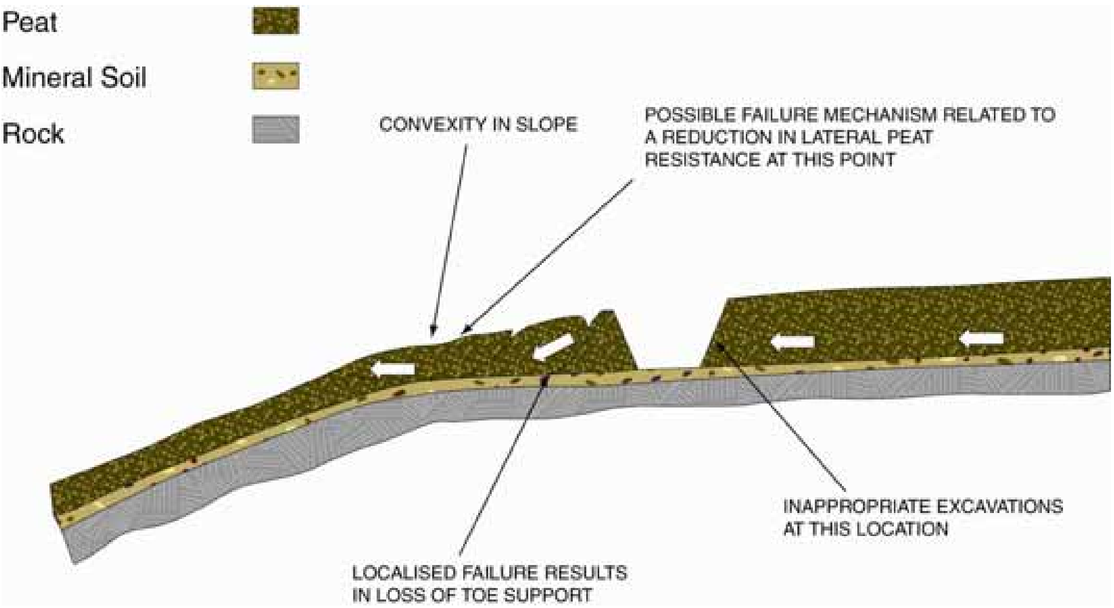


Figure 8; Typical failure due to excavation adjacent to convex slope.

4. CLIMATIC ISSUES

It has been established that high rainfall is a major contributory factor in the mass movement of peat. The recent report (Winter et al. 2005) for the Scottish Executive, summarises information on climatic conditions. As our climate is changing, this information is particularly useful for the designer/contractor of a road within a peatland. Traditionally, the key periods for road construction over peat, were seen as:

- the summer months, with low rainfall, and
- cold winters with hard frosts.

The designer/contractor can no longer rely on this and must put measures in place to deal with the "summer storm" and programme work outwith the wettest winter months.

The changes in climate will also have an effect on peat slope stability. It can be no longer assumed that slopes that have been stable up to now will continue to be so.

The following key points are taken from the report:

"*Scotland, in terms of rainfall, can be divided into east and west (see Fig 9). Data presented by the Meteorological office (anon 1989) indicates the following key comparisons:*

- *In the east rainfall generally peaks in August while in the west the maximum rainfall levels are reached during the wider period September to January.*
- *Although rainfalls in the west are relatively low in August, they increase from a low point in May.*

Both of these scenarios indicate that the soil may be undergoing a transition from a dry to a wetter state at or around August, with an increased potential for debris flow and other forms of landslide activity." (Winter et al. 2005)

Analysis of recorded UK and Irish peat mass movements by Warburton et al. (2004) shows that roughly half occur in the months of June, July and August indicating a similarity with other land slide activity. In practical terms, the designer and contractor must have measures in place to accommodate a "summer storm".

In the future, climate change will have an effect that the designer must take into account. The following points, which are taken from the climate change model predictions for Scotland in the 2080s, will have an effect in relation to the mass movement of peat. (htttp://www.ukcip.org.uk, and Winter et al. 2005)

- Precipitation will decrease in summer but increase in the winter.
- The models are less good at predicting localised summer storms.
- Localised summer storms are believed to be at least partially responsible for triggering half of the peat slides recorded to date.
- Predicted changes in the number of "intense" wet days generally indicate a net increase of less than one day per annum by the 2080s,
- There will be slightly fewer intense wet days in the summer but more in the winter.
- Extreme storm event rainfall levels are predicted to increase by between 10% and 30% by the 2080s.
- Intense winter rainfall will increase slightly more than the above, and that of spring/autumn by slightly less.
- Summer extreme rainfall depths are predicted to increase by between 0% and 10%
- The occurrence of snow and the associated contribution to groundwater is predicted to increase.

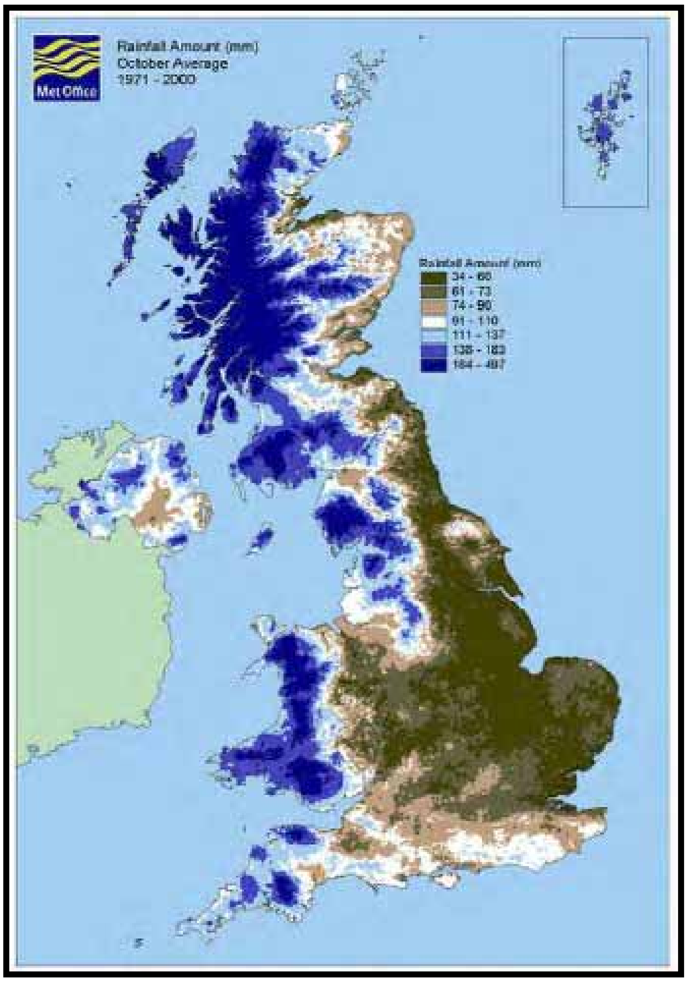


Figure 9: Example of 30-year monthly average rainfall data for October (Meteorological Office)

5. PEAT CHARACTERISTICS AND PROPERTIES

5.1 Formation

The properties of peat vary from peatland to peatland and even from point to point in the same deposit. Such variations are associated with the origins of the peat, the type of plant from which it was derived, the mineral content of the deposit, and the amount of decay or humification that has occurred. The variability of peat with depth is particularly noticeable because peat deposits are generally formed in layers, which may differ considerably in their nature. Fresh fibrous peat (Acrotelm) tends to occur near the top of a deposit while the lower layers (Catotelm) are frequently composed of soft, relatively dense and highly decayed material. Within the catotelm, decayed tree stumps, or peat with a plate-like structure derived from decayed rushes, may be encountered. However, the most important feature is the water content and for a peatland area to develop and grow, the water input must exceed or equal the water output. The water content of peat can range from 500-2500% of the dry weight.

Hobbs (1986) described the development of a peatland as "The Wetland Succession." There are 3 stages in this process.

- "Rheotrophic" stage in which the mire develops in a body of water, with nutrients provided by the feeding streams, ground water and seepage. Initially the mire process starts with inorganic sedimentation such as silts and clays but this becomes increasingly more organic as the detritus from plant communities build up in the basin floor.

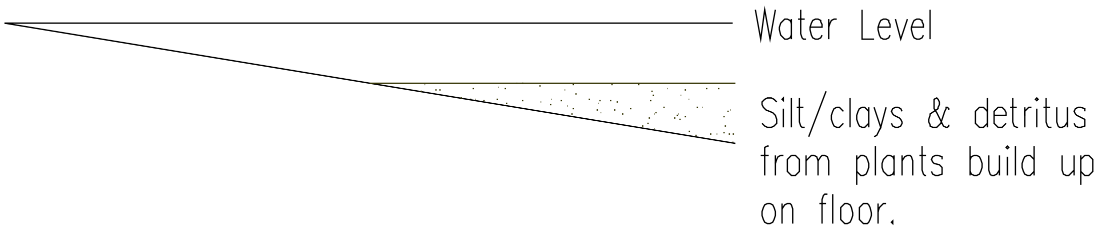


Figure 10: Rheotrophic Stage

- Transitional" stage is characterised by a steady growth of the bog upwards and out of the standing water and into a raised bog. During this stage the bog is still influenced by local water levels but is beginning to rely on rainwater for sustenance.

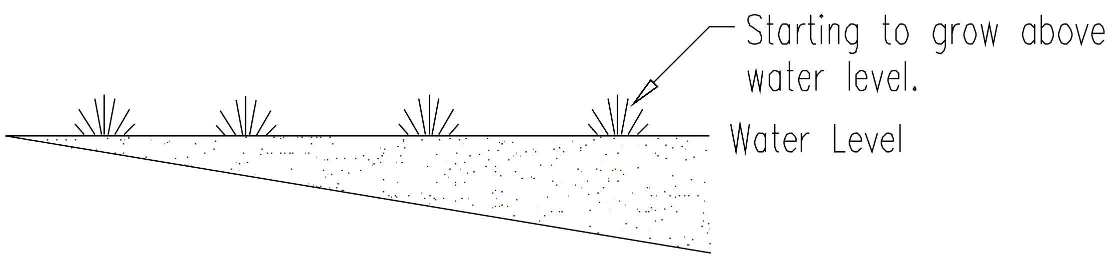


Figure 11: Transitional Stage

- “Ombrotrophic” stage is when the raised bog is out of the body of water and its survival is entirely dependent on precipitation. This type of bog can also form on a suitable surface under favourable wet climatic conditions without the need for standing water and is termed a blanket bog.

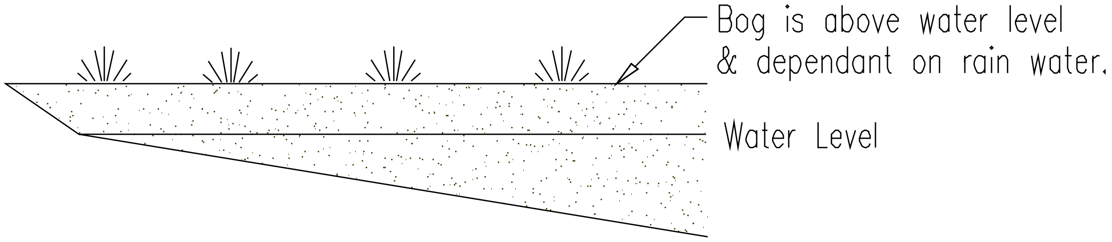


Figure 12:Ombrotrophic stage

“Blanket bogs”, which dominate in Scotland, belong to the latter ombrotrophic stage, (Raeymaekers,G.,(1998). These bogs require:

- an annual rainfall of at least 1000mm with
- a minimum of 160 rainy days per year

and have a growth rate of 1mm per year. Their characteristics are similar to raised bogs but with a more even and less deep peat layer over the landscape (Munro 2005). For example, it is estimated that about 70% of the Forestry Commission land containing peat have peat depths of less than 2 metres.

In general, the greater the altitude of a peatland, the thinner the peat layer. The peat is only likely to have any great thickness over large and deep depressions in relatively flat topography. Provided the slope is not excessive, peat will accumulate wherever the drainage is impeded. A slope of 20^0 appears to be the limiting gradient for deep peat. Most slides occur in side slope angles between 2 and 20^0. (Agec 2004)

5.2 Classification

Peats fall into three basic groups:

- amorphous-granular peat;
- course fibrous peat; and
- fine fibrous peat",

reflecting the morphology of the parent peat deposit (Radforth 1969). Amorphous-granular peats have a high colloidal mineral component, which tend to hold the contained water in an adsorbed state around the grain structure. The two fibrous peat types are woodier and hold most of their water within the peat mass as free water.

This simple basic classification can be further subdivided by physical description of the "degree of humification" based on the hand squeezing of samples as set out by Von Post,L. & Granland,E., (1926) (see Table 3).

Degree of Humification	Identification Guide
H1	Completely unconverted and mud-free peat which when pressed in the hand only gives off clear water. Plant remains are easily identified.
H2	Practically unconverted and mud free peat which when pressed in the hand gives off almost clear colourless water. Plant remains are still easily identifiable.
H3	Very slightly decomposed or very slightly muddy peat which when pressed in the hand gives off marked muddy water, but no peat substance passes through the fingers. The pressed residue is thickish. Plant remains have lost some of their identifiable features.
H4	Slightly decomposed or slightly muddy peat which when presses in the hand gives off marked muddy water. The pressed residue is thick. Plant remains have lost more of their identifiable features.
H5	Moderately decomposed or muddy peat. Growths structure evident but slightly obliterated. Some amorphous peat substance passes through the fingers when pressed but, mostly muddy water. The pressed residue is very thick.
H6	Moderately decomposed or very muddy peat with indistinct growth structure. When pressed approximately 1/3 of the peat substance passes through the fingers. The remainder extremely thick but with more obvious growth structure than in the case of unpressed peat
H7	Fairly well decomposed or markedly muddy peat but the growth structure can just be seen. When pressed about half the peat substance passes through the fingers. If water is also released this is dark and peaty.
H8	Well decomposed or very muddy peat with very indistinct growth structure. When pressed about 2/3 of the peat substance passes through the fingers and at times a thick liquid. The remainder consists mainly of more resistant fibres and roots.
H9	Practically completely decomposed or mud-like peat in which almost no growths structure is evident. Almost all the peat substance passes through the fingers as a uniform paste when pressed.
H10	Completely decomposed or mud peat where no growth structure can be seen. The entire peat substance passes through the fingers when pressed.

Table 3: Degree of Humification of Peat (Source: *Von Post,L. & Granland,E., (1926)*)

5.3 Hydrology and Permeability

In a peatland, the movement of water is the controlling ecological feature, and the subject has initiated many specialist papers. The importance and the influence of water during and after road construction within a peatland cannot be overstated. Failure to manage the flow of water may initiate a peat slide.

Hydraulically the two peat layers behave differently:

- The "acrotelm", the upper layer, has a high hydraulic conductivity and a variable water content, is rich in peat–forming aerobic bacteria and has a live matrix of growing plant material (Ingram 1978). The depth varies between 100-600mm and in engineering terms is known as the "mattress" due to its tensile strength (Hobbs 1986).
- The "catotelm" has a water content invariable with time, a small hydraulic conductivity, is not subject to air entry, and is devoid of peat forming aerobic micro-organisms (Ingram 1978). Its permeability tends to be less than the acrotelm, decreasing with depth and humification (Hobbs 1986).

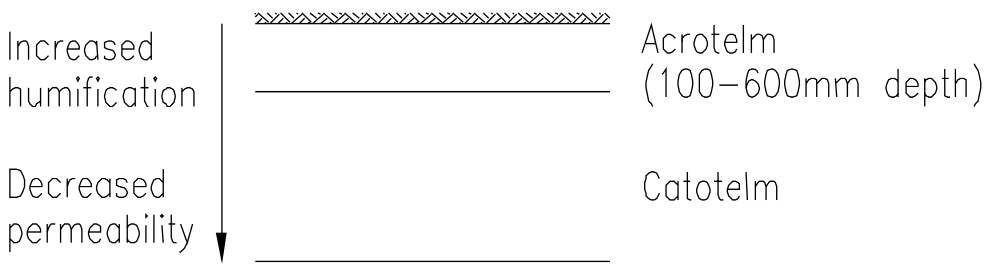


Figure 13: Peat layers

The flow of water in a peatland is poorly understood. However, it is accepted that run-off follows the saturation-excess overland flow model. This occurs when the soil profile is completely saturated and the water at the surface is a mixture of fresh rainwater and waters that return to the surface from travelling within a slope. (Holden & Burt 2004).

Most of this flow is contained within the acrotelm with little in the catotelm. However, blanket bogs tend to develop internal water flow system "pipes", which originate with the water flowing along the ground surface in hollows under the peat. These flows develop into sub-surface pipes or channels of 50-100 mm across, although they can be up to 1 metre across. These pipes are well connected to the surface, and can deliver significant water volumes to the base of the peat. Collapse of these pipes is not uncommon forming a system of surface drainage gullies or "hags". This causes the adjacent peat to dry and crack, resulting in further dissection forming the pool and hummock structure which is typical of a blanket bog (Hobbs 1986). During this dissection and cracking process irreversible changes take place within the colloidal matrices of the peat. The result of this is that the peat will only be capable of taking up a fraction of the water it previously contained if immersed again.

Pipe failures can initiate bog-bursts and subsequently slides. Failure can be as a result of pressure build up within the pipes caused by heavy rains. Significantly, developments on the peatland can also contribute to this type of event due to the loading of the peat during embankment construction or the deposition of peat spoil.

Figure 14: Pipe Entrance

Figure 15: Bog Burst from Pipe Exit

Figure 16: Collapsed Pipe Ceiling

Water flow within a blanket bog tends to converge towards the steepest local slope and an appreciation of the underlying topography will help to understand water flow beneath the peat. Natural hollows in the underlying topography can also collect water, forming reservoirs of peat with a very high water content that can lead to difficulties for the unwary engineer.

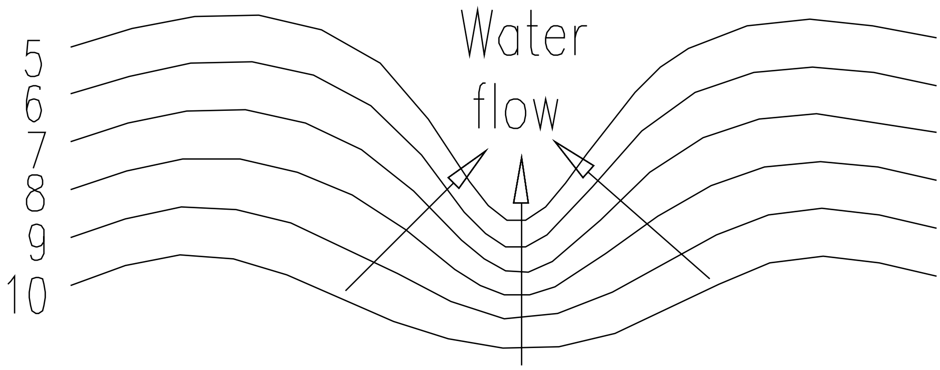


Figure 17: Mapping of Underlying Topography can provide an indication of water flow

5.4 Shear Strength

Shear strength of peat is dependent on its moisture content, degree of humification and mineral content (the higher the moisture content and humification, the lower the shear strength; the higher the mineral content, the higher the shear strength (Munro 2005)). As a general rule, shallow peat, due to its more fibrous nature, is likely to have greater strength than more humified peat at depth (AGEC 2005). However, due to the variable nature of peat and the difficulties in obtaining good representative samples from the field, laboratory testing can only give indicative results. A number of in situ field tests (such as the vane test) are available for peat, but all have limitations. When working with peat, it is important to recognise that if the area is loaded too quickly without allowing time for water pressures within the pores to be released, the peat will essentially have the shear strength of water i.e. 0kPa. In the literature, reported strengths show a great deal of variation, however according to MacFarlane (1969), the in situ shear strength will generally be within the range of 4 to 20kPa at peat depths of less than 2 m.

5.5 Density

The dry density of peat is very low, usually in the order of 80-160 kg/m³. Since most peats are waterlogged, the density is closely related to the moisture content. Thus the engineering properties associated with high moisture contents usually correspond with those associated with low dry densities and vice versa.

5.6 Effect of Forest Planting on a Peatland

Considerable research has been carried out on this subject, mostly related to improving growth rates, however the hydrology of the peat land is of interest to both the forester and the engineer. Forest roads and, more recently, windfarm access roads are being constructed over blanket bogs that have been planted with trees. Research on changes to a blanket bog in Rumster Forest (Shotbolt et al 1989) indicate that tree planting and the subsequent active management of the forest can have a significant impact on the properties of the peatland. At Rumster, these forest activities resulted in an overall lowering of the forest floor, indicating a decrease of the peat depth and a lowering of the water table. This led to an increase in the acrotelm thickness causing cracking, and an increase in the bulk density of the peat. The permeability of the catotelm decreased, possibly due to compression caused by the weight of the trees. Draining a peatland, a normal activity in the management of forests, can cause settlement of the peat surface (by consolidation and secondary compression). Maintaining a drainage channel at least 1 metre below the water table for at least 1 year can cause approximately 15% settlement (Hobbs 1986).

The Rumster research also indicated that there was a buffer zone outwith the forest area where a gradual rise in level occurred from the forest to the original blanket bog level. This zone (which was up to 40 metres) had the effect of forming a slope from the surrounding blanket bog towards the forest. This is of interest to the engineer as cracking within the buffer zone and forest floor can lead, in periods of heavy rain, to water ingress increasing the risk of peat slide. As the trees grow and the compression effect on the catotelm increases there may also be an increased risk of collapse of the internal drainage channels. This could increase the risk of peat slide or lead to the formation of water reservoirs within the peat - and a further cause for concern to the engineer!

6. CONSTRUCTION METHODS AND CONSIDERATION OF SLIP RISK

The method of construction employed on a peatland will have a significant impact on the risk of slip. The most common methods used to construct low cost roads over peat in Scotland are “Excavation and Replacement” and “Leaving the peat in place”. There are other methods that can be used but their costs tend to preclude them from the types of road used in Forestry and Windfarm development.
During the construction of the road it is important to note that, as a peat is loaded, the permeability reduces dramatically. The peat compresses and the free water within the pores is squeezed out into the adjacent unloaded bog. As the load is applied, the voids within the loaded peat reduce and the inter-colloidal particle attractions increase with a consequent rapid reduction in the permeability through the peat (Munro 2005).

6.1 Excavation and Replacement

In this method the peat is removed, usually side cast, and the mineral sub soil exposed, shaped, and an embankment constructed on it. This method is, in construction terms, almost fail-safe, and is restricted only by the depth of peat. In low cost roads, the economic depth, is approximately 2metres. The risk is thus moved to the adjacent peat, and to the placement method used for the excavated peat spoil.

In this method of construction the designer and contractor have several design features to address;

- The excavated faces can be left nearly vertical. This is an unusual feature of peat, particularly considering the water content. As the peat is excavated, the phreatic surface drops with a consequent reduction in the hydrostatic pressure.
- Localised failures can occur on the edges of the excavation. These may be as a result of encountering peat areas of high water content. Such failures are usually minor, but can trigger retrogressive failure.
- The collapse of an excavated face can lead to the siltation, or more significantly damming of a ditch, watercourse or pipe. This could, in turn, trigger a slide event.
- Alteration of water flows will increase the slide risk by increasing the flow or pressure within the pipe system.
- The drainage of the road and the surrounding peatland area must be carefully planned to ensure water flows away from the road.
- The position of the road on a side slope is critical. This is particularly true on convex slopes where the excavation could remove toe support thus triggering a slip.
- The placement of excavated peat requires careful attention. Until the pore water dissipates, the stability of the peat is at its most vulnerable.

Figure 18: Excavating Peat from Road line

Figure 19: Peat Excavated and side-cast from roadline

6.1.1 Assessment of Peat Slip When Loading the Adjacent Peat During the "Excavation and Replacement Method"

In the process of excavating and side casting peat, the risk of peat slip moves to the adjacent area of peat. It is normal practice that the stability of the area of loaded peat can be assessed using *the 'infinite slope analysis'* model, (Skempton and DeLory,1957). The infinite slope analysis is suited to translational sliding. This is considered to be the common mode of failure for peat slides. This model provides for a factor of safety (FoS) for the excavation process.

The definition of the FoS in this model is the ratio of ground resistance to disturbing forces. Where the ground resistance is equal to the disturbance forces, the FoS is unity and the ground would be considered to be on the point of failing. A FoS greater than 1.0 would indicate a stable slope and an FoS of less than 1 would indicate an unstable slope.

BS 6031:1981, The Code of Practice for Earthworks (BSI 1981), provides advice on the design of both temporary and permanent earthworks. It states that, for a 'first time failure' with a good standard of site investigation, the design factor of safety (FoS) should be 1.3 to 1.4.

As this analysis ignores passive resistance at the toe of a potential sliding failure, the FoS is a conservative estimate which, considering the vagaries of peat, is to be welcomed. The analysis makes use of total stresses, a situation that applies to the short-term conditions occurring during both construction, and for a time thereafter until the construction induced pore water pressures have had time to dissipate. Undrained shear strength values (Cu) for peat are used for total stress analysis.

A common formula for the FoS ,(Barnes,2000) is as follows:

$$F = Cu/(\gamma z \sin\beta \cos\beta)$$

Where;

- **Cu** = Shear strength of the peat (kPa)
- **γ** = Bulk weight of peat (kN/m^3)
- **z** = Depth of Peat (m)
- **β** = Angle of sliding plane (degs)
- **F =** Factor of Safety

The depth of peat and the angle of sliding plane can be determined from probing. Low shear strength values should be used in critical areas, but higher values based on experience may be used for the less critical scenarios.

Table 3 illustrates a FoS calculation from 3 locations following the application of 4 load cases. The number of load cases can vary, according to the depth of peat. It is unlikely that this method of construction will be used where peat depths exceed 2metres, but there may be deep pockets of peat that have to be dealt with. This type of calculation provides guidance on the height to which the peat can be deposited on the adjacent peat and this information can be provided to the excavator driver. This process can be refined as the peat is excavated, using actual depths of peat as opposed to those from the peat probing survey.

The load cases are:

- No Load
- 1metre of peat added
- 2 m peat added
- 3m peat added

Location Ref	Angle of Sliding Plane (deg)	Peat Depth (m)	Peat Strength (kPa)	Bulk Unit Weight (kN/m^3)	No Load FOS	1m Peat added FoS	2m peat added FoS	3m Peat added FoS
A1	4.2	2.3	8	10	4.7	3.3	2.5	2.06
A2	3.6	1.8	8	10	7.1	4.6	3.4	2.65
A3	15	1.0	8	10	3.2	1.6	1.1	0.8

Table 3: FoS Calculation Example

Although the risk of peat slip at locations A1 and A2 is low, management is required to avoid any small localised slip. This can only be determined as the excavation is ongoing and the staff involved must have a clear procedure to follow. Although the peat is shallow at location A3, if for some reason the excavated peat is deposited to a depth of more than 2metres, there is an increased risk of peat slip. This might seem to be unrealistic considering the peat on the road line is only 1 metre deep. However, where time is an issue, operators are often keen to deposit the peat as close to the excavation as possible. There may also be environmental reasons determining the method by which the peat is deposited. For example, to minimise the impact on the peatland the road may have to be built within in as narrow a corridor as possible. There are many situations where the peat could be deposited at greater depths than the excavated depth. A mechanism must be in place both to control the operation and to inform those that are carrying out the work of the implications of not complying.

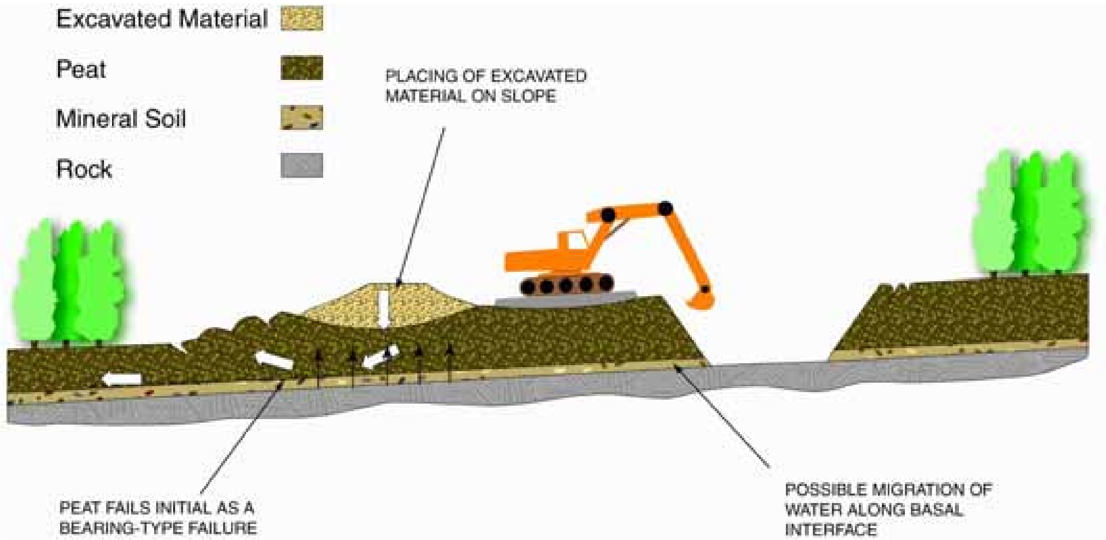


Figure 19:Typical Peat Failure during excavation process

6.2 Leaving the Peat in Place

When dealing with peat depths in excess of 2metres, it normally becomes more cost effective to leave the peat in place and utilise the strength of the in-situ peat. The most commonly used methods in low volume/low cost roads are:

- Placing an embankment over a layer of timber/timber brash as recommended by the Forestry Commission. This method involves laying a raft of timber directly onto the peat surface and then constructing an embankment on top of the raft. In the short and medium term this provides a reinforcement effect to the base of the embankment, aids stability, and can reduce differential settlements and lateral stresses on the peatland surface.
- Constructing an embankment using geotextiles and geogrids. Geotextiles act as a separator and filter and are placed directly onto the peat surface. However, it is geogrids that provide reinforcement to the base of the embankment. Geogrids also aid stability and can reduce differential settlements and lateral stresses on the peatland surface.

Both the above methods have the benefit of reducing the amount of material required to build the embankment. However, when using geogrids, better quality of fill is required to provide the necessary interlocking effect.

Figure 20: Spreading Material on Timber Mat

Figure 21: Spreading Material on Geogrids

Figure 22: Shaping Formation "Floated" on Trees

Figure 23: Compacting Completed Road

In relation to peat slip, there are advantages to using the 'peat left in place' method as it appears that the peat internal drainage channels, and the water flow within the peatland, are not unduly affected. However this is not always the case and risks can arise due to:

- Rupture of the Acrotelm due to the use of large sharp rocks with subsequent loss of tensile strength.
- Overload, and the subsequent shearing of the peat during the delivery of embankment materials;
- The possible collapse of the internal drainage channels;
- Positioning the road on or adjacent to a convex side slope;
- Failure of the peat affecting embankment stability, which can cause tilt of the road;
- Long term settlements, which reduce the permeability of the peat.

The above can be significant contributory factors in instigating peat slide.

Little can be done to predict collapse of the internal drainage system. However, the risk of collapse due to overloading can be estimated, and a suggested management process to limit the risk of failure follows.

6.2.1 Assessment of the Embankment Loading Rate During the "Leaving the Peat in Place Method of Construction"

Under load, peat 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 an increasing share of the embankment load as it increases in strength.

This complex process can take up to 30 years. However, primary consolidation, which accounts for about 50% of the final settlement, is to be expected during the initial construction process. In large volume roads, where settlement is a major concern, a more detailed assessment is required to predict settlement. One such method used in Sweden uses the moisture content of the peat to determine the deformation of the embankment. (Carlsten 1988) However in a low volume road, the primary consolidation can be dealt with during the construction phase, and subsequent settlement can be accommodated as part of normal maintenance operations.

When building an embankment over peat, it is Forestry Civil Engineering procedure to limit the weight of the vehicles delivering material to the embankment head. This can be in the form of vehicles carrying, say, 50% capacity at the start of the process. As the embankment height increases, the peat consolidates and pore water pressures stabilise, and the weights can be increased. This method does reduce the risk of inducing peat failure but it increases the time to build and the cost of the road. In a windfarm development, time is often the critical element and pressure is on the developer/contractor to complete the project quickly to start generating income. As mentioned in **5.4,** if the embankment is constructed quickly with no regard to the shear strength of the peat, failure is inevitable. Construction of an embankment on peat is only possible if the "drained strength" of the peat is utilised. If loaded too quickly, without time for water pressures to be released, the loaded peat will effectively have the shear strength of water, i.e 0kPa.

Research carried out in Ireland and the Northern periphery Region (RoadexII) on the recovery of low volume public roads over peat suggests that such a road may take 20 minutes to recover from the effects of a 44tonne, 6 axle vehicle. Determining this period of recovery is a complex process that is the subject of considerable research and is outwith the scope of this report. However the results from the research to date, combined with informed observational techniques, can produce a satisfactory method for constructing an embankment on peat.

A "loading rate", i.e. the time for materials to be delivered at the embankment head, can be determined prior to the construction process and amended as the embankment is constructed. As the embankment is being constructed, the appearance of the road and surrounding land must be monitored for:

- Increased rate of sinking or tilting
- Rising of adjacent peat
- Cracking on the peat surface

- Rise in water levels.

The monitoring system need not be complicated. A line of levelled pegs and visual monitoring is acceptable. However, to prevent injury or an environmental incident, it is important that there is a robust procedure in place should it become apparent that a collapse is imminent.

Using the results from visual monitoring of the embankment construction, a graph can be created to show the relationship between the shear strength of the peat and the time between loads. As the process is empirical, I have shown the relationship as a simple linear progression in Figure 15. This is because to the variable nature of peat, and the difficulties of installing a definitive monitoring system during the construction process. However this method provides a simple but effective mechanism for monitoring the impact and applying a risk management procedure.

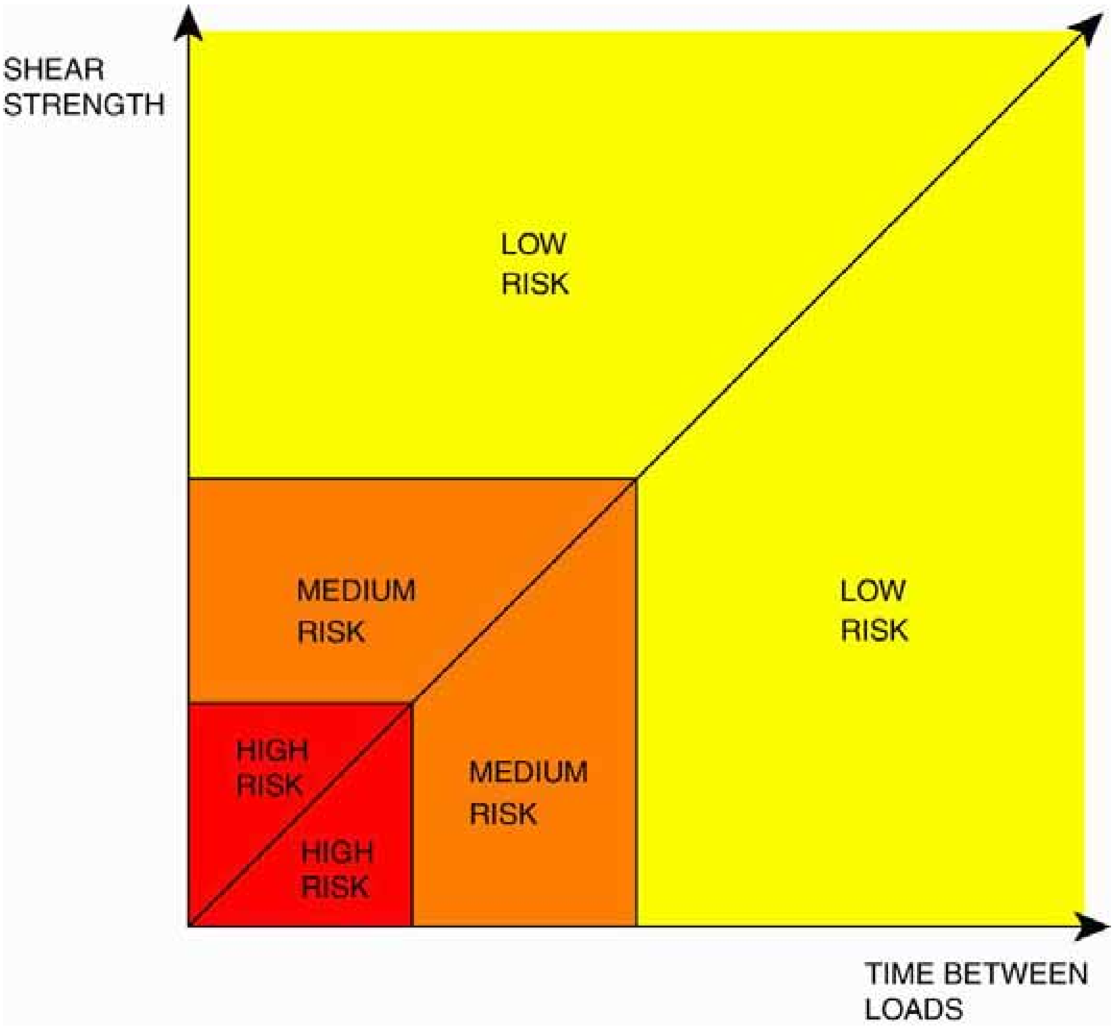


Figure 15: Graph Showing Relationship Between Shear Strength and Time Between Loads

It can be seen from Figure 15 that reducing the time between material deliveries would increase the risk of peat failure with the possibility of initiating a peat slip. However, increasing the time between the loads allows the pore water pressure to dissipate into the adjoining peat, thus reducing the risk.

7. SITE INVESTIGATION

7.1 Introduction

As previously mentioned, peat is a highly variable material and some site investigation is essential to assist in the design of the road and limit the consequence of a peat slip. There is normally an economic limit to the amount of site investigation that can be carried out for low volume/low cost roads due to budgetary and time constraints placed on the engineer. It is, however, vitally important that sufficient importance is placed on a suitable investigation of the site. The results of any investigation will form the basis of the Geotechnical Risk Register. To put costs in perspective, a high quality report with site investigation and laboratory testing for a part of a windfarm development may cost in the region of £30,000. In Forestry terms, this sum would build approximately 750metres of road.

7.2 The Geotechnical Risk Register

The management of geotechnical risk, like all risk management, is a dynamic process that has to continuously monitor and review risks as they are discovered. The Risk Register assists this dynamic management process by systematically considering all identified risks in a structured fashion. This generally involves 4 phases.

- The identification of the hazard
- Assessing the probability of it occurring and its impact if it did
- Managing the risk identified
- Allocating responsibility and action

Good communication between client, designer and contractor is needed for this process to work. Where all parties can agree to sign up for co-operation the risks identified within the project have a better chance of being considered early and contingency planning put in place to meet the risk.

7.3 The Site Investigation

A typical site investigation for the construction of a low cost road within a peatland might include the following:

1. Project Appraisal:
- Review and agree remit
- Initial design
- Identify objectives of site investigation

2. Gather Information:
- Walkover survey
- Desk Study – Literature and data review
- Review information gathered
- Carry out Initial Impact assessment
- Identify if Ground investigation required

3. Detailed Assessment:
- Design Ground investigation
- Manage ground investigation
- Produce factual report on results
- Analyse and design/re-design
- Form basis for Geotechnical Risk Register

Typically the above process will involve a range of engineering and environmental disciplines. The process is dynamic, and there can be benefits from merging one after the other or even repeating (James 2004).

7.4 Suggested Guidelines for Site Investigation for a Windfarm Development

7.4.1 The Appraisal

The positions of the generating turbines are the critical elements in the efficiency and cost effectiveness of a development. They are also high cost in relation to the construction of the site access roads. As a result, the road layout can at times appear to be a perfunctory operation. The business case for an access road layout within a windfarm development can be stated simply as 'to link the turbine sites to a suitable public road minimising the total length and investment required'. Having said that, the aim must be to produce the most cost effective roading solution. This will require that the environmental issues be weighed alongside with the engineering and financial criteria.

7.4.2 Gathering Information

This is not straightforward and typically, needs to be revised and repeated to get the most cost effective and risk acceptable route. There is a tendency for planners and designers, when confronted with an area of blanket bog, to use surface contours for designing the access roads. This practice, on a side slope, if used, is usually flawed. Both the underlying mineral soil level and peat surface level must be known before the position and design of the road can be fixed. The vehicles transporting windfarm equipment demand tight tolerances, particularly with regard to longitudinal gradient. Typically, the overall gradient is limited to 10% and vertical curves vary from 300- 500metre radius. If only surface contours are used to determine the road corridor, problems can arise in the construction of the road. For example, if an excavation method is used, the underlying mineral soil level becomes the determining level for the route to avoid the unnecessary excavation or import of materials. This can lead to the route moving outwith the original planned corridor. For the 'peat left in place' method, differential settlement of the loaded peat can be expected which could lead to difficulties with regard to the vertical curves

In this "gathering of information" phase, the walk over survey and Desk Studies are key elements in the process.

The Desk Study will bring together what is known about the site. In a typical peat land area there may be little information, but the following sources should prove helpful and assist the walk over survey:

- Ordnance survey and other maps-current and historical
- Geological maps, memoirs and boreholes (British Geological Survey)
- Aerial Photos
- Satellite Data
- Estate records,
- Weather Reports
- Heritage Organisations
- Environmental Organisations
- Interest groups/local societies
- Publications and periodicals re-past slips or extreme weather events
- Previous reports

Without exception, an engineering 'walk over' survey is necessary and would be expected to pick up and map the following features which we know to contribute to the movement of peat:

- Peat depth
- Side slope angle
- Convexity of Slope
- Hydrology (Surface)
- Hydrology (Sub Surface)
- Previous Instability
- Cracking
- Peat Workings
- Peat Classification

A fuller description of the above features along with an example survey sheet is shown in Appendix 2and 3. Both sheets can be used in the field.

7.4.3 Initial Impact Assessment

Results from any ecological and environmental surveys will be essential information for the road design and layout. All the information is considered and evaluated to arrive at an initial impact assessment and to determine whether ground investigation work is required. A suggested method for this evaluation follows.

The possible road corridor is examined, and using the results and information gathered, a preliminary assessment made of the environmental impact should a mass movement of peat occur. The project can then be divided into "Environmental Impact Zones", using criteria determined from the surveys. For example, from Table 4, a proposed access road within 100metres of a public road has a "Medium" Environmental Impact. Several environmental issues may only be relevant at certain times of the year e.g. nesting bird sites, and the impact status may alter during the period of the project. A more complete example is shown in Appendix 1.However it is difficult to arrive at definitive distances as the criteria will be site dependant. Typically the depth of peat and slope angle will influence the *flow characteristics* of the peat should a change occur in the peat matrix. At present no method exists to accurately plot this flow but some estimation is required. SEPA recommend a buffer zone of 10-15 metes between watercourse and construction activities. I suggest that in a deep peat site with a side slope this 10-15-metre buffer is insufficient

Suggested Criteria	**Environmental Impact**
Proposed Road within 50m of property/people Proposed Road within 50m of public road Proposed Road within 50m proximity to water courses Proposed Road within 50m of other Environmental issues	High
Proposed Road within 100m of property/People Proposed Road within 100m of public road Proposed Road within 100m Proximity to water courses Proposed Road within 100m of other Environmental issues	Medium
Proposed Road within 150m of property/People Proposed Road within 150m of public road Proposed Road within 150m Proximity to water courses Proposed Road within 150m of other Environmental issues	Low

Table 4: Assessing the Environmental Impact

7.4.4 Detailed Assessment

The design of the ground investigation follows assessment of the environmental impact zones. This would be dependent on the category of environmental impact and a cost analysis. For a "High Environmental Impact" area it is likely that the following investigations would be considered:

- Further Detailed Probing;
- Possible Ground-probing Radar investigation;
- Mapping the underlying mineral soil profile; and
- Trial excavation pits

The information provided by the above would allow more detailed design and assessment to be carried out, albeit with the caveat that any information gathered would only be indicative of the characteristics and properties of the peat.

Testing peat in the field or in the laboratory is difficult, and any results must be viewed with caution. Furthermore, "Low volume /Low cost" will almost certainly mean that large scale testing is not cost effective.

Technique	Norway	Finland	Sweden	Scotland
Borehole	Used occasionally	Used occasionally	Used occasionally	Used occasionally
Probing	Used Regularly	Used Regularly	Used Regularly	Used Regularly
Undisturbed Sampling	Used Regularly	Used occasionally	Used occasionally	Used occasionally
Shear Vane	Used Regularly	Used Regularly	Used Occasionally	Used occasionally
Standard /cone penetrating test	Used occasionally	Used Regularly	Used occasionally	Used occasionally
Swedish Weight Sounding	Used occasionally	Used Regularly	Used occasionally	Not Used
Georadar	Used occasionally	Used Regularly	Used occasionally	Used occasionally

Table 5: A Summary of Ground Investigation Methods Used by the Roadex Partner Areas (Munro 2005)

All the peat failures mentioned in Table 2 (p7) suggest a change in the consistency of the peat due to water ingress. The values obtained by using any of the above ground investigation methods (Table 5) may not be relevant and a more cautious view should be taken. (Back analysis of the peat at the Derrybrien site carried out by AGEC Ltd (2004) calculated that the shear strength of the peat had a value of 2.5kPa.). To arrive at a conservative design, a range of values can be used depending on the Environmental Impact should a failure occur (Table 6).

Environmental Impact	Shear Strength (kPa)	Water Content (%)
High	2.0 –5.0	2000- 2500
Medium	5.1 –10.0	1500-2000
Low	10.1-15.0	500-1500

Table 6: Range of Shear Strength and Water Content Values

In "High Environmental Impact Areas", a low value of shear strength and a high water content value should be used. For low and medium environmental impact zones, higher values, which can be based on observations and monitoring during the construction of the road, can be used to arrive at a cost-effective design.

.

Receipt of the final report may well allow further re-design of the road corridor and suggest possible construction methods. The results can then be used to form the basis of the Geotechnical Risk Register. The suggested measures can be put in place for the contractor and the process re evaluated throughout the construction process.

8. PROPOSED METHODOLOGY FOR EVALUATING THE LIKELIHOOD OF PEAT SLIP DURING ROAD CONSTRUCTION.

Due to the variability of peat and the uncertainties associated with natural peat movement, it is very difficult (if not impossible) to arrive at a definitive mathematical method of predicting movement. The addition of the construction process makes prediction even more difficult. However, if the factors which, we know to contribute to peat movement are considered and evaluated, measures can be designed into the construction process to lessen the impact on natural peat movements.

The factors will have been picked up in the survey report (as described in 7.4.2). These can be listed in a table and assessed, linking the measured value to the likelihood of contributing to a peat slide. Using experience and knowledge we have about slide mechanics, control measures based upon allocated probabilities can be input into the construction process. Tables 7 and 8 give an indication of probabilities.

Contributory factor	Method of Assessment	Value/Indicator	Probability of Contributing to Peat Movement	Control Measure Required
Moisture Content	Experience or if available laboratory results.	0-500%	Negligible	No
		500-1000%	unlikely	No
		1000-1500%	probable	Yes
		1500-2000%	Likely	Yes
		2000-2500	Very Likely	Yes
Peat Depth	Measured using peat probes, Ground Radar, Trial Pits	0- 0.5 metre	Negligible	No
		0.5 – 1.0	Unlikely	No
		1.0 – 1.5	Probable	Yes
		1.5 – 2.0	Likely	Yes
		2.0+	Very Likely	Yes
Slope Angle	Indicative from probing, or ground radar, measured when peat excavated.	$0\text{-}3^0$	Unlikely	No
		$4\text{-}9^0$	probable	yes
		$10\text{-}15^0$	Likely	Yes
		$16\text{-}20^0$	Very Likely	Yes
		20^0 +	High Risk	Yes
Cracking (Tension and Compression)	Visual. Very Subjective also linked to depth of cracks. It also unlikely that cracking would exceed 20% of road corridor length	No Evidence	Negligible	No
		0-5% Road Length	Unlikely	No
		5-10% Road Length	Probable	Yes
		10-15% Road Lengths	Likely	Yes
		15-20% Road Lengths	Very Likely	Yes
Underground Hydrology (Pipes/Channels)	Visual. Very difficult to evaluate, but evidence may exist in the form of exit/entrances to underground channels. Collapsed ceilings of pipes may be evident	None Evident	Negligible	No
		Few	Unlikely	No
		Frequent	Probable	Yes
		Many	Likely	Yes
		Continuous/Significant	Very Likely	Yes
Surface Hydrology (Gully Channels, Hags and pool, systems, Wet Flushes, Water courses)	Visual. Interpretation may be necessary due to weather conditions at time of survey..	None evident	Negligible	No
		Few	Unlikely	No
		Frequent	Probable	Yes
		Many	Likely	Yes
		Continuous/Significant	Very Likely	Yes
Evidence of Previous Slips	Visual survey .No evidence would be no slips. Significant many small or one large slip	No Evidence	Negligible	No
		Little	Unlikely	No
		Frequent	Probable	Yes
		many	Likely	Yes
		Continuous/Significant	Very Likely	Yes
Weather	This can be evaluated from weather records for the area. With the suggested change in climate this feature may become a significant contributory factor. Research from Ireland has shown that most slides occur during a period of high rainfall following a dry period.	Previous Very Dry Period in excess of 5years.	Negligible	No
		Previous Very Dry Period within 4-5 years.	Unlikely	No
		Previous Very Dry Period within 3-4years.	Probable	Yes
		Previous Very Dry Period within 2-3 years.	Likely	Yes
		Previous Very Dry Period within 1-2 years.	Very Likely	Yes

Table 7: Contributory Factors with Probability Values

Probability values used in the above table are arrived at as follows:

Probability (P) Value	
Very Likely	>75%
Likely	50 – 75%
Probable	25-50%
Unlikely	10- 25%
Negligible	<10%

Table 8: Probability Values

8.1 Example

Using Table 7, an assessment of the complete project can be compiled to form part of the Geotechnical Risk Register. In the following example, taken from Appendix 1, a section of road is in a "High Environmental Impact" zone between turbine bases D -E. The following features have been identified:

- Moisture content of 2000-2500%;
- Sub Surface Slope angle of 4^0;
- Surface Cracking over 1% of road length;
- Little evidence of underground channels;
- Frequent evidence of surface flow;
- No evidence of previous slips;
- Very dry periods in previous 1-2 years; and
- Average depth of peat 1.3 metre.

The Geotechnical Risk Register for this section could then be as set out as in Table 9. The process is dynamic and, to work effectively, it requires continuous evaluation over the life of the project.

Location	Environmental Impact Area	Contributing factor	Likelihood of Contributing to peat slip	Control Required
Road between Turbine Bases D-E	High	Moisture Content	Very Likely	Yes
		Slope Angle	Probable	Yes
		Peat Depth	Probable	Yes
		Cracking	Unlikely	No
		Weather	Very Likely	Yes
		Evidence of Sub Peat water flow	Probable	Yes
		Surface Water Flow	Probable	Yes
		Evidence of previous slips	Unlikely	No

Table 9: Example of Geotechnical Risk Register for Road between Turbine Base D – E.

From the above table, moisture content, slope angle, weather, peat depth, surface water flow and sub peat flows require mitigation measures in the road design. Suggested measures could be:

- Re-evaluate the line of the road
- Further detailed ground investigation;
- If the **Excavation and Replacement** construction method is to be used, the FoS calculated, as outlined in 6.1.1;
- If the **Leaving the Peat in Place** construction method is to be used, the embankment-loading rate to be monitored and managed as described in 6.2.1;
- Monitoring system put in place to assess movement of road and surrounding peatland area;
- Maintain hydrology of area;

- Dry spells in previous years will make the site vulnerable to storms. Monitoring of weather required. Programme work in High Environmental Impact Areas to avoid the months of August/September and January/February;
- Use of experienced geotechnical staff for site investigation;
- Use of experienced contractors and trained operators to carry out the work.

9. SUMMARY AND RECOMMENDATIONS

9.1 Summary of What is Known About the Mass Movement of Peat.

Peat, as we have described, is a highly variable and unpredictable material. However, the following is now known about the natural and construction induced mass movement of peat:

- Peat is a highly variable material and there are no guarantees;
- Peat movement is a natural process of a peatland;
- Movement occurs during major rainfall events, frequently following summer storms;
- Failures may be more frequent as climate changes and as development moves into peatland areas;
- It cannot be assumed that a slope that has been stable will remain so.
- Little structural damage has occurred in Scotland to date other than the blocking of a small number of transport corridors;
- Environmental impact can be high;
- Failures are initiated by translational sliding;
- Failures occur in areas of very wet peat;
- Failure of internal drainage and high groundwater conditions are key factors;
- An increase in porewater pressure lowers the stability of the slope;
- Failure tends to occur at or just above the peat / mineral interface;
- In extreme events, peat can act as a liquid and travel over very shallow slopes;
- Geotechnical reports are expensive and may not provide all the answers;
- Assessment requires an integrated approach including all professional disciplines;
- The rate of construction can have a major influence, i.e by overloading;
- Locating a road adjacent to a convex slope/break in slope can induce failure;
- Road excavation can trigger failure due to loss of toe support;
- Constructing a road on a peatland can collapse the internal drainage system;
- Deposition of peat can induce failure.

9.2 Recommendation for the Risk Management of Peat Slips

Prior to planning approval, it is reasonable to expect a developer to carry out a full scoping appraisal to satisfy both planners and environmental interests. It is important that only competent and experienced contractors carry out the work. Therefore, developers must have a sound mechanism for appointing contractors on "Best value" principles if the results are to be accepted and believed by Planning Authorities. The appraisal should be based upon:

- The use of experienced and competent personnel;
- An engineering walk over survey;
- A full Desk Study;
- Mapping of features and establishing hydrology for the area;
- Identifying and zoning the project for environmental impact should a slip occur;
- Using underlying substrate surface angle to calculate side slope angle in High and Medium Environmental Impact areas;
- Using low shear strength values in "High" Environmental Impact Areas, and high water content values to produce conservative designs;
- Mapping underlying Hydrology in "High" impact areas;
- Using calculation methods in 6.1.1 and 6.2.1 to assist in determining method of road construction;
- Setting out the basis for the Geotechnical Risk Register;
- Setting out a plan for the control of silt; and
- Setting out contingency plan should a peat movement occur.

If a development receives planning consent, prior to commencing construction work the developer must:

- Appoint experienced and competent contractors;
- Allocate sufficient time for the project; and
- Be aware that decreasing the construction time increases the risk of initiating a peat movement.

During the Construction process the developer has a duty to:

- Set up and maintain monitoring systems;
- Ensure method statements are followed; and
- Revise and amend the Geotechnical Risk Register as construction progresses.

Throughout the approval process, Local Authorities, Scottish Executive and Land Managers have a responsibility to understand:

- Peat is a highly variable material and there can be no guarantees;
- At present there is no detailed modelling to assess peat slope stability;
- Geotechnical reports are expensive and developers require assurance before committing funds;
- Construction Method statements for initial planning consents must not stifle innovation; and
- Resources need to be in place to ensure monitoring systems are maintained and method statements are followed up.

9.3 FINALE

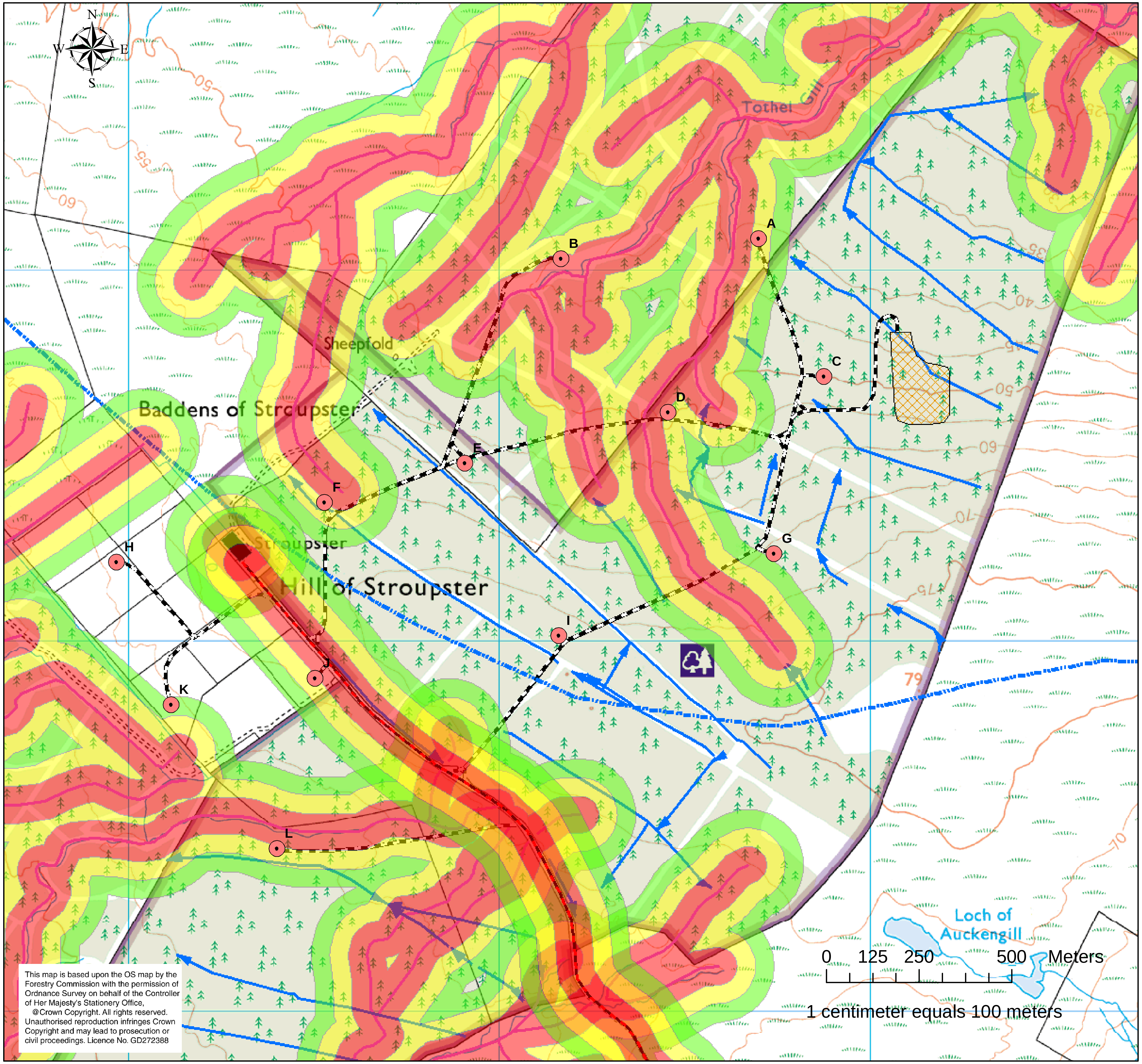
This report allows an engineer to adopt a practical and hands on approach, to minimise the "Slip" impact when constructing a low volume/low cost road over a peatland. It is not exhaustive and there is considerable research ongoing at present by major consultants and research bodies into understanding the movement, hydrology and morphology of peat. In the future there will be significant developments in ground radar and satellite imagery linked to computer modelling. This will allow detailed mapping of peatlands to provide detailed modelling of peat movement. But in the meantime ……

REFERENCES

1. AGEC Ltd (2005), *Report on Additional Peat Study Selected Turbine Sites*, Prepared for Npower renewables Ltd (unpublished).
2. Barnes, G.E., (2000), *Soil Mechanics, Principles and Practice*, 2nd Edition, Palgrave Macmillan.
3. British Standards Institute (1981). BS 6031 : 1981 *Code of practice for earthworks*.
4. Carlsten,P., (1988), *Peat Geotechnical properties and up-to-date methods of design and construction*, State-of-the Art-Report Preprint, Statens geotekniska institute Report 215
5. Clayton, C.R.I. (2001), *Managing Geotechnical Risk*, Prepared under the DETR Partners in Technology Programme for The Institution of Civil Engineers, London.
6. Davidson, K.T. (1991), *Construction of Roads Over Peat*, Forestry Commission, (unpublished)
7. Durward,G. (1991), *Forest Roads over Peat*, Summary of Seminar, Forestry Commission (unpublished)
8. Dykes, A.P. and Kirk K.J. (2000), *Initiation of a Multiple Peat Slide on Cuilcagh Mountain*, Wiley Interscience (website).
9. Fleming, D. (2003), *Irish Engineers Battle Huge Landslide*. New Civil Engineer
10. Fleming, D. (2003), *Check Dams Halt Galway Windfarm Landslide* Ground Engineering
11. Forestry Civil Engineering (2000), *The Forestry Civil Engineering Handbook*; Forestry Commission, (unpublished)
12. Griffiths, R. (2004), *Peat Slides in County Mayo, Ireland,* Forestry Civil Engineering ,Peebles (unpublished)
13. Hobbs, N.B. (1986), *Mire Morphology and the Properties and Behaviour of Some British and Foreign Peats*. Q.J Eng. Geology. Volume 19.
14. Holden, J. and Burt, T.P., (2003), *Hydrological Studies on Blanket Peat: the Significance of the Acrotelm – Catotelm Model*, British Ecology Society, Journal of Ecology 91, 86-102
15. Ingram, H.A.P.(1978), *Soil Layers in Mires; Function and Terminology* ,Journal of Science, 29, 224-227.
16. James, A. (2004), *The Importance of a Good Site Investigation*, Forestry Civil Engineering, Peebles (unpublished)
17. Landva, A.O. (1980), *Vane Testing in Peat* Canadian Geotechnical Journal
18. Lyon, J. (?), *Experience of Working in Soft Ground*, Coilte Teo, (Unpublished)
19. Maltby, E. and Proctor, M.C.F. (1996*), Peatlands:Their Nature and Role in the Biosphere*. In: Lappalainen, E. (Ed.), Global Peat Resources. International Peat Society, Kukkalantie, pp. 11 –19.
20. MacFarlane, I.C. (ed.), (1969), *The Muskeg Engineering Handbook*, National Research Council of Canada.
21. Munro, N. (2005), *Dealing With Bearing Capacity Problems on Low Volume Roads Constructed on Peat*. ROADEX II Northern Periphery.
22. Nichol, Dr D. (2005*), Preliminary Peatslide Risk Assessment Glenkirk Windfarm Project*, Prepared for Eurus Energy UK Ltd, (unpublished)
23. Owende, P.M.O., Martin, A., O'Mahony, M.J. and Ward, S.M. (2004), *Effects Of Logging Traffic On Forest Access Roads With Peat Subgrade*, Forest Engineering Unit, University College, Dublin. (unpublished)
24. Patterson, G. and Anderson, R. (2000), *Forests and Peatland Habitats*, Guideline Note, Forestry Commission, Edinburgh.
25. Radforth,N.W. (1969), *The Muskeg Engineering Handbook*, National Research Council of Canada.
26. Raeymaekers,G., (1998), *Conserving mires in the European Union* ,LIFE-Nature Project
27. Roadex Project (1998-2001) Northern Periphery, CD-ROM (ROADEX I)
28. Roadex Project (2001-2005) Northern Periphery, DVD (ROADEX II)
29. Ryan, T., Phillips, H., Ramsay, J. and Dempsey,J. (2004*), Forest Road Manual, Guidelines For The Design, Construction And Management Of Forest Roads*, National Council for Forest Research and Development,Ireland.
30. Scottish Executive (2003), *Scoping Opinion For The Proposed Windfarm At Beinn An Tuirc Extension;* (Scottish Executive Website)
31. Shetland Islands Council A970 (November 2005), *Report on Channerwick Peat Slides*, Halcrow Group Ltd. (Unpublished)
32. Shotbolt, L., Anderson, A.R. and Towend, J. (1998), *Changes to Blanket Bog; Rumster Forest, Caithness*, Forestry Commission, (unpublished)
33. Skepton, A
34. Tallis, J. (2001), *Bog Bursts*; University of Manchester, 2001,I nstitute of Biology, Biologist (website)

35. The Department of Environment, Transport and Regions, (1998), *Eurocode 7 – A Commentary*, The Building Research Establishment and Arup
36. The Highways Agency (2002), *HD22/02 Managing Geotechnical Risk* Design Manual for Roads and Bridges
37. Tressider, J.O. (1966), *A Review of Existing Methods of Road Construction Over Peat*. Road Research Laboratory, Road Research Technical Paper No 40, HMSO
38. Verbruggun K. (2004), *Landslides in Ireland*; Geological Society of Ireland (website)
39. Von Post,L. & Granland,E., (1926) *Peat Resources in Southern Sweden*, Sverges geoligiska undersokning
40. Warburton, J. Holden, J. and Mills, A.J. (2004) *Hydrological Controls Of Surficial Mass Movements In Peat*. Earth- Science Reviews 67 (2004) 139-156.
41. Winter, Dr M., MacGregor, F. and Shackman, L. (2005), *Scottish Road Network Landslides Report*, Scottish Executive,Edinburgh
42. Worman, C and McMorrow, J., (2003), *Water Quality- Blanket Peat; Dark Peak Fieldwork*; University of Manchester, (unpublished, Website)

Appendices



This map is based upon the OS map by the Forestry Commission with the permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office, ©Crown Copyright. All rights reserved. Unauthorised reproduction infringes Crown Copyright and may lead to prosecution or civil proceedings. Licence No. GD272388

Title

Appendix 1

Information

Legend

- Stroupster_Turbines
- Stroupster_House
- Burn
- Public_Road
- Stroupster_Road
- stroupster drains
- Stroupster Watershed

Environmental Impact Zones

- High (50m buffer)
- Medium (100m buffer)
- Low (150m buffer)

Author	David Straube	Date	16/11/05
Checked by	[signature]	Date	16/11/05
Scale	1 : 10000	Filename	R:\Extenal Work\Stroupster

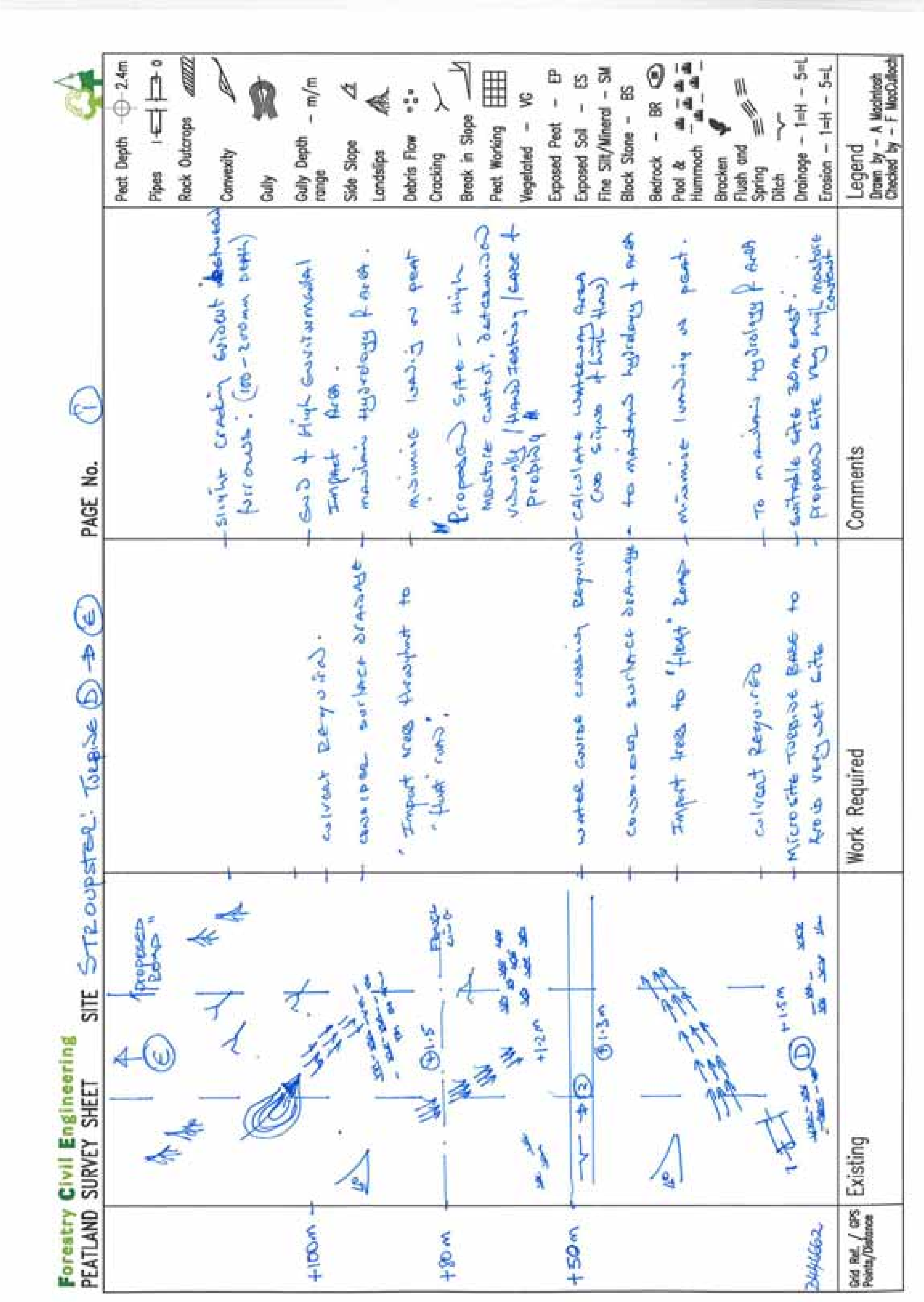
Forestry Civil Engineering
Area Civil Engineer N(S)
North Scotland
1 Highlander Way
Inverness Business Park
Inverness IV2 7GB
Tel: 01463 232811
Fax: 01463 714978

Frank MacCulloch
Area Civil Engineer

E-Mail:
frank.macculloch@forestry.gsi.gov.uk

Forestry Civil Engineering

Appendix 2


Forestry Civil Engineering
PEATLAND SURVEY SHEET
SITE STROUPSTER: Turbine D → E
PAGE No. 1

Grid Ref. / GPS Points/Distance	Existing	Work Required	Comments
			- slight cracking evident between furrows: (100-200mm depth)
+100m		culvert Required.	- GWD + High Environmental Impact Area.
		consider surface drainage	- maintain hydrology & area.
+80m		' Import trees throughout to "float" road'.	- minimise loading on peat
			Proposed site – high moisture content, determined visually / Hand testing / case + probing
+50m		water course crossing Required	- Calculate waterway area (no signs of high flow)
		consider surface drainage	- to maintain hydrology + area
		Import trees to 'float' road	- minimise loading on peat.
		culvert Required	- To maintain hydrology & area
3446662		- Microsite Turbine base to avoid very wet site	- suitable site 30m east.
			- proposed site very high moisture content

Appendix 3: Contributing Factors to Peat Movement and their measurement.

Contributing factors to Peat Movement	Reason	Measurement
Peat Depth	As the depth of peat increases humification increases. shear strength and permeability decrease	The most common method to determine peat depth is peat probing. This involves pushing proprietary steel rods into the peat until refusal. It provides a good indicator of peat depth but results can be suspect when underlying layers of tree roots or gravel deposits within the peat are encountered. The effort taken to drive the peat can give an indication of water content and possible underground channels. The process is labour intensive but it is essential in every project to give the designer and contractor a "feel" for the site. It is expected that developments in ground penetrating radar linked to a ground positioning system will become the method of determining peat depth in the future.
Side slope angle	Research from Ireland(AGEC 2004) indicates that most failures occur between 4 -12^0	The surface angle and sub-surface side slope angle is required. The surface angle can be measured using a clinometer and with further peat probing can produce the sub surface angle. From the results it is possible to produce a simple contour map of the peat sub-surface to give some indication as to the direction of water flow beneath the peat surface. Side slope angle can assist in determining the possible run out distance, should a movement occur.
Convexity	Research has indicated that most movements occur on a convex slope or on a break of slope. (Agec 2004, Warburton et al 2004)	This can be picked up visually on walk over survey and measured using a clinometer. The position is critical, as any road must be situated away from this feature. This can be difficult to pick up when surveying through forests and interpolation may be required. Aerial Photographs and O S maps can assist.
Hydrology (Surface)	Peatlands do not provide flood attenuation. It is essential to design any road drainage to prevent triggering any peat movement	Pool and hummock systems, gullies and wet flushes should all be recorded to assist in the design of the surface hydrology. The siltation plan will require this detail. Previous man made drainage can lead to an increase in the water flow and subsequent pore water pressure in the discharge area, particularly if not maintained
Hydrology (Sub Peat)	Failures are frequently associated with the increased pressure and collapse of the sub surface pipe network	Locating internal drainage routes is problematic if not unrealistic. The plotting of entrances and exits can give an indication of the incidence of underground drainage paths. It is likely that an area with no obvious surface channels at the bottom of a side slope will have an internal drainage system. The collapsed ceilings of an internal system, show as depressions in the peat and this can be a possible position indicator of a pipe.
Previous Slips	An area with previous slips will be prone to slips in the future.	Recent slips can be easily identified due to the presence of exposed layers of peat, however old slips may be more difficult as the vegetation grows over. Particularly difficult to discover in tree cover, however tree angle is a good indicator. An area that has grown over may appear to flat on the top of the slip appearing to provide a good location for a road. Obviously the positioning of the road on this feature would be inappropriate.
	Crevises/Cracking (Tension and compression)	Cracking can provide an indication of impending or previous peat movement. This cracking allows water to penetrate the peat matrix to the peat/mineral interface initiating failure. Linking cracks to the underlying mineral surface contours can provide information on the indication of the direction
Peat workings	Can remove toe support and induce retrogressive failure	The presence of peat workings is a common feature and should be noted within the survey area.
Classification	Provides Indication of peat properties	The Von Post classification is the most commonly used (see Table 3) Experience dependant.