Analytical Analysis

The following analysis uses an analytical approach to determine factors of safety to quantify the risks of peat slides and local rotational failure or engulfment of excavations occurring. A separate qualitative risk assessment is described in the report followed by a Discussion of these analyses. The findings of each will be used to establish overall risks of peat movement occurring at various locations across the site.

The Scottish Guidance suggests the application of Infinite Slope Stability Analysis be employed to gauge the stability of peat on slopes and determination of the relevant Factor of Safety (FoS).

The analysis is based on a theoretical infinite slope which considers the resistance to failure (dependent on shear strength) and the active gravitational force (dependent on peat depth, weight and slope).

The minimum required FoS for stable slopes is 1.3, as specified in BS 6031:1981: Code of Practice for Earthworks (BSI, 1981). Where undrained parameters are used a FoS of 1.5 may be preferable.

For this purpose the following modified formula, (Bromhead, 1986) is proposed:-

$$FoS = \frac{Cu + (\gamma - m\gamma_w) z \cos^2 \alpha \tan \phi'}{\gamma z \sin \alpha \cos \alpha}$$

where

FoS = Factor of Safety

C_u = Undrained Shear Strength (kPa)

γ = Bulk Unit Weight of Saturated Material (kN/m^3)

m = height of water table as a fraction of peat depth (m)

γ_w = Unit Weight of Water (kN/m^3)

ϕ = Angle of internal friction (deg)

z = Depth to Failure plane (Assumed depth of peat) (m)

α = Slope angle (deg)

However, the inclusion of the modification for water table fluctuation has the effect of increasing the factor of safety when the water level rises. Ultimately the peat slope is most vulnerable when water is not present and the density of the peat material is at its highest.

For this purpose the basic form of the equation has been employed and the most conservative value of density for the peat, (approximately 15kN/m^3 - where it has a relatively high clay content), has been considered. In general peat will be much less dense than this figure, especially if dry.

However, in an effort to mimic the most extreme and unstable conditions that could possibly exist, a high value of density has been considered, which would return the most limiting values.

Infinite Slope Analysis

The formula used in this analysis to determine the FoS, for the undrained condition for a given slope, weight and strength of material (Bromhead, 1986), is therefore as follows:

$$FoS = \frac{Cu}{\gamma z\ Sin\alpha\ Cos\alpha}$$

Where,

FoS = Factor of Safety

C_u = Undrained Shear Strength (kPa)

γ = Bulk Unit Weight of Material (kN/m^3) – assumed, for saturated peat, to be at 15kN/m^3

z = Depth to Failure plane (Max depth of peat measured in vicinity of turbine) (m)

α = Slope angle (deg)

The maximum slope of approx. 10^0 at the proposed turbine positions has been employed for the calculations.

The results are summarised in the table below:

ID	Slope (deg.)	Z (m)	Cu (kPa)	Factor of Safety Sliding
T1	5	3.40	10[1]	**2.25**[2]
T2	5	2.60	18	4.43
T3	10	3.50	16	1.78
T4	10	2.10	12	2.23
Substation	22.5	0.70	12	3.23

Table 4 – Analytical Assessment of Infinite Slope Stability

Stability of Excavations in Peat

As an additional observation it is useful to consider the stability of excavations within the peat at the site of proposed cuttings and / or excavations. The following formula allows a determination of the maximum height of a vertical slope that should be considered when excavating in peat soils.

a) Maximum height of vertical excavated faces:

The maximum height of an excavated vertical peat or soil face can be determined using Coulomb's expression for critical vertical height,

$$Hc = \frac{4Cu}{\gamma}.\frac{cos\varphi}{1 - sin\varphi}$$

Where

Hc = Critical Vertical Height (m)

[1] In-situ testing Undrained undertaken by WGS Ltd. in April / May 22

[2] Minimum FoS highlighted

C_u = Undrained Shear Strength (kPa)
γ = Bulk Unit Weight of Material (kN/m^3)
φ = Angle of Internal Friction of Material (°)

Taking the most conservative approach, assuming a zero angle of internal friction (φ=0°), and the lowest shear strength (measured at a proposed turbine location during dry conditions) of 5kPa with a safety factor of 2 applied to it, the **safe vertical height would be 0.97m**.

This estimate of safe vertical height is taken into consideration in the risk assessment, construction method statements and mitigation measures. Based on the above analysis, it is likely that the cut faces of peat, with height is in excess of this figure, will require support at certain locations, either by battering back to 45° for shallower faces or use of sidewall support / plating in the case of deep excavations for hard-standings. The excavation of peat will therefore have to be managed in order to mitigate against local peat face or slope failure.

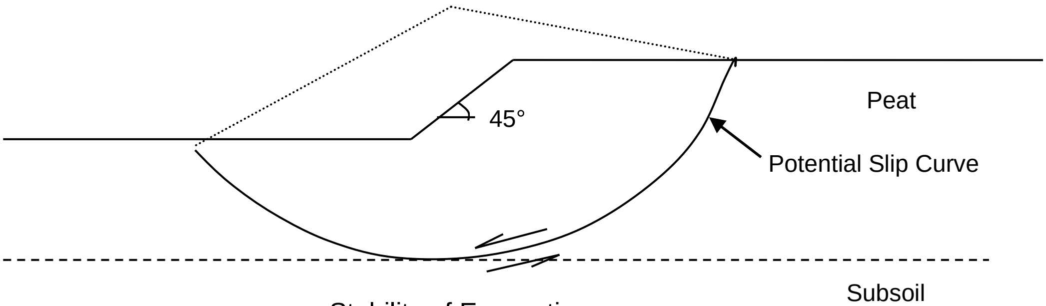
b) Rotational failure of battered back slopes:

Although this is not specifically considered in the Scottish Guidance, assessment of the potential stability of the face of a battered back excavation enables the engineer to determine the level of risk appropriate to excavations.

It should be noted that local rotational failure is not restricted to sloping areas and can also occur on flat areas. This can result in engulfment of excavations which is a significant risk hazard and presents additional construction difficulties.

The theory is based on the short-term stability of excavations and involves dividing the peat mass into vertical slices and determining the overall horizontal and moment equilibrium about a potential slip curve tangential to the base of the peat (see diagram below) by equating the active and resisting forces along that curve.

A Factor of Safety is therefore determined for both horizontal equilibrium and moment equilibrium. The lower of these values is tabulated in Table 5.



Stability of Excavations

The analysis of the stability of excavations in peat was conducted to assess the potential risk of failure. In theory local failure is likely to occur where the Factor of Safety (FoS) is less than 1, but locations with a FoS of less than 1.3 should be given due attention.

The analysis is based on the following equilibrium equations [Bishop, 1955]:

$$FoS = \frac{\sum_1^n c_u \Delta b sec^2 \alpha}{\sum_1^n \Delta W tan\alpha} \quad \text{(Horizontal equilibrium)}$$

$$FoS = \frac{\sum_1^n c_u \Delta b sec\alpha}{\sum_1^n \Delta W sin\alpha} \quad \text{(Moment equilibrium)}$$

where Δb, ΔW and α are the width, weight and slope (of slip face to horizontal) of each vertical slice taken through the slip curve diagram above.

For 45 degree cut faces, within the maximum peat depth encountered at the proposed development site, the following rotational stability FoS has been calculated. See Table 4 overleaf.

ID	Slope (deg.)	Cu (kPa)	Max Face Height Considered[3]	Factor of Safety Rotational Failure
T1	5	10	3.40	**> 1.3**
T2	5	18	2.50	**> 1.3**
T3	10	16	3.50	**> 1.3**
T4	10	12	2.10	**> 1.3**
	22.5	12	0.70	**> 1.3**

Table 5 – Analytical Assessment of Stability of Excavations

Factors of safety are in excess of 1.3. Therefore, by battering back of the peat faces to slopes of 45° will render the risk of peat instability to be LOW for the peat strengths and slopes measured at the proposed Letter Wind Farm site.

[3] Maximum height used relates to the maximum height only within the construction zone. i.e. where excavations are likely to take place.