1. Global Slope Stability Assessment

1.1. Material properties

For the purposes of performing a global slope stability assessment, material properties are assessed for the poorer soil at the site, being Topsoil and Soft and Firm Silt and Clay. The results of the GII (2020) investigation are used along with standards guidance and comparable experience to derive the required properties.

Undrained shear strength parameters are estimated based on the descriptions in the trial pit logs (e.g. very soft, soft, firm, etc.) and the guidance of BS 5930 (1999) which has traditionally been used to correlate soil consistency observations with undrained shear strength. Due to the inherent disadvantages of this method, conservative assumptions are made.

Based on the plasticity indices reported in Soft Clay and Silt in the GII (2020) ground investigation, which were typically 10 to 16, the correlation presented in BS 8004 (2020) and comparable experience is used to derive effective stress parameter values $\varphi' = 27°$ and $c' = 2$kPa for the stability analysis of the Soft Clay and Silt. The same parameter values are assigned to the Topsoil.

A bulk weight of 18kN/m^3 is assumed for the Topsoil, Soft Clay and Silt, and Firm Clay and Silt based on comparable experience and guidance from BS 8002 (2015).

The derived and assumed characteristic parameter values for the Topsoil and Soft and Firm Clay and Silt are summarised in Table 1.

Table 1 – Characteristic parameter values for slope stability assessment

Material / Parameter	**Topsoil**	**Soft Clay and Silt**	**Firm Clay and Silt**
Bulk Weight (γ_k) [kN/m^3]	18	18	18
Undrained shear strength ($c_{u,k}$) [kPa]	15	15	25
Effective cohesion (c'_k)	2	2	2
Effective angle of shearing resistance (Φ'_k) [degrees]	27	27	27

1.2. Method of assessment

A deterministic slope stability assessment was carried out based on the results of the ground investigation carried out on the site and the contours of the ground. The partial factors from Eurocode 7 (I.S. EN 1997-1:2005 + AC:2013 + NA+2015) are used to derive design parameter values and hence the results are reported in terms of Overdesign Factor rather than traditional Factor of Safety. This is considered the appropriate way to present results as Eurocode 7 is considered the best and most appropriate available standard or code of practice at present.

Stability of a soft soil slope is dependent on several factors working in combination. The main factors that influence slope stability are slope angle, shear strength of soil, depth of soil, pore water pressure and loading conditions. An adverse combination of factors could potentially result in a landslide. An adverse condition of one of the above-mentioned factors alone is unlikely to result in failure. To assess the factor of safety for a landslide, an undrained and drained analysis has been undertaken to determine the stability of the slopes on the site where soft soils are present.

The infinite slope model (Skempton and DeLory, 1957) is used to combine these factors to determine a factor of safety for slope stability. This model is based on a translational slide, which is a reasonable representation of the dominant mode of movement for most failures in soft soils on hill sides.

The formula used to determine the factor of safety for the undrained condition is as follows (Bromhead, 1986):

$$ODF = \frac{c_{u,d}}{\gamma z \sin\beta \cos\beta}$$

Where:

- ODF = Overdesign Factor (analogous to Factor of Safety, however ODF > 1.0 indicates satisfactory stability.
- $c_{u,d}$ = Design value of undrained shear strength.
- γ = Bulk unit weight of material.
- z = Depth to failure plane assumed as depth of soft or firm soil.
- β = Slope angle.

The formula used to determine the factor of safety for the drained condition is as follows (Bromhead, 1986):

$$ODF = \frac{c'_d + (\gamma z - \gamma_w h_w)\cos^2\beta \tan\phi'_d}{\gamma z \sin\beta \cos\beta}$$

Where:

- ODF = Overdesign Factor (analogous to Factor of Safety, however ODF > 1.0 indicates satisfactory stability.
- c'_d = Design value of effective cohesion.
- γ = Bulk unit weight of material.
- z = Depth to failure plane assumed as base of soft or firm soil.
- γ_w = Unit weight of water.
- h_w = Height of water table above failure plane
- β = Slope angle
- φ' = Effective stress friction angle

For the drained analysis the level of the water table above the failure surface is required to calculate the factor of safety for the slope. Since the water level in soft soil can be variable, it is not feasible to establish its precise location throughout the site. Therefore a worst case approach was assumed and the water level is taken to be at the surface.

Based on an analysis of the contours of the site and the ground conditions, three locations were selected for assessment:

1. Near Turbine 14
2. Near Turbine 16
3. Between Turbine 20 and Turbine 21

At Location 2 near T16, two scenarios were assessed, stability in the “soft” soil layer and stability in the “firm” soil layer. “Condition 1” represents in-situ conditions while “Condition 2” represents the stockpiling of up to 1.0m of Clay or Silt on the ground surface during construction.

The results of the analyses carried out are shown in Table 2 and Table 3. All soil parameters and loadings are factored in accordance with Eurocode 7 Design Approach 1 Combination 2, which is the most onerous.

Table 2 - Slope stability assessment results for the drained condition

Turbine / Location	Slope	Effective stress cohesion (worst case)	Effective stress friction angle (worst case)	Bulk unit weight	Soft Clay or Silt Depth (m)	Water level in Soft Clay or Silt	Surcharge Equivalent Placed Fill Depth (m)	Eurocode 7 DA1.2 Overdesign Factor for Load Condition	
	β (deg)	**c'_d (kPa)**	**φ (°)**	**γ_d (kN/m³)**	**Condition 1**	**(m)**	**Condition 2**	**Condition 1**	**Condition 2**
T14	8.8	1.4	27.00	18	1.2	1.2	3.5	**1.94**	**2.83**
T16 - soft	10.5	1.4	27.00	18	0.7	0.7	3.0	**1.88**	**2.55**
T16 - firm	10.5	1.4	27.00	18	3.0	3.0	5.3	**1.40**	**1.99**
T20 to T21	5.5	1.4	27.00	18	1.3	1.3	3.6	**3.05**	**4.49**

Table 3 - Slope stability assessment results for the undrained condition

Turbine / Location	Slope	Undrained shear strength (worst case)	Bulk unit weight (worst case)	Soft Clay or Silt Depth (m)	Surcharge Equivalent Placed Fill Depth (m)	Eurocode 7 DA1.2 Overdesign Factor for Load Condition	
	β (deg)	**$c_{u,d}$ (kPa)**	**γ_d (kN/m³)**	**Condition 1**	**Condition 2**	**Condition 1**	**Condition 2**
T14	8.8	10.71	18	1.2	3.5	**3.28**	**1.11**
T16 - soft	10.5	10.71	18	0.7	2.0	**4.75**	**1.66**
T16 - firm	10.5	17.86	18	3.0	4.3	**1.85**	**1.29**
T20 to T21	5.5	10.71	18	1.3	2.6	**4.80**	**2.40**

All Overdesign Factors were greater than 1.0, indicating that the stability of the soil is satisfactory in the both short term (undrained) and long term (drained) condition.

Hence, a *"low"* risk rating for soft soil instability is appropriate for the proposed development, subject to normal design and construction mitigations and controls to secure the short- and long-term stability of the proposed earthworks including turbine and substation foundations and access roads. In particular, drainage must be carefully managed. Detailed design will take into consideration the measures required for the stability of each earthworks location.

2. References

Bromhead, E.N. 1986. *The Stability of Slopes.* Surrey University Press.

BS 5930:1999. *Code of practice for site investigations.* London, British Standards Institution.

BS 8002:2015. *Code of practice for earth retaining structures.* London, British Standards Institution.

I.S. EN 1997-1:2005 + AC:2013 + NA+2015. *Eurocode 7: Geotechnical design - Part 1: General rules (Including Irish National Annex).* Dublin, National Standards Association of Ireland.

Skempton, A. W. & DeLory, F. A. 1957. *Stability of natural slopes in London Clay.* Proc 4th Int. Conf. On Soil Mechanics and Foundation Engineering, Rotterdam, vol. 2, pp.72-78.