FEHILY TIMONEY
30 YEARS

CONSULTANTS IN ENGINEERING, ENVIRONMENTAL SCIENCE & PLANNING

GEOTECHNICAL & PEAT STABILITY REPORT

BRACKLYN WIND FARM

Prepared for: **Bracklyn Wind Farm Ltd**

Date: **July 2021**

Unit 6, Bagenalstown Industrial Park, Bagenalstown,
Co. Carlow, R21 XW81, Ireland
T: +353 59 9723800 E: info@ftco.ie

CORK | DUBLIN | CARLOW

www.fehilytimoney.ie

GEOTECHNICAL & PEAT STABILITY ASSESSMENT REPORT
BRACKLYN WIND FARM

User is responsible for Checking the Revision Status of this Document

Rev. No.	Description of Changes	Prepared by:	Checked by:	Approved by:	Date:
0	Draft for Comment	IH	PJ	BdeH	05.02.21
1	Update following comments	IH	PJ	BdeH	11.05.21
2	Final	IH	PJ	BdeH	02.07.21
3	Final	IH	PJ	BdeH	15.07.21

Client: Bracklyn Wind Farm Ltd

Keywords: Geotechnical, Peat Stability, Peat Failure, Ground Investigation, Risk Assessment

Abstract: Fehily Timoney and Company (FT) were engaged by Bracklyn Wind Farm Ltd to undertake a geotechnical assessment of the proposed Bracklyn wind farm site with respect to peat stability. As part of the geotechnical assessment of the proposed development, FT completed walkover surveys at the site. The findings of the geotechnical and peat stability assessment showed that the site has an acceptable margin of safety and is suitable for the proposed development.

TABLE OF CONTENTS

1. NON-TECHNCIAL SUMMARY ... 1

2. INTRODUCTION ... 1

2.1 Fehily Timoney and Company ... 1

2.2 Project Description ... 1

2.3 Peat Stability Assessment Methodology ... 1

2.4 Peat Failure Definition ... 3

2.5 Main Approaches to Assessing Peat Stability ... 3

2.6 Peat Stability Assessment – Deterministic Approach ... 4

2.7 Applicability of the Factor of Safety (Deterministic) Approach for Peat Slopes ... 5

2.8 Assessment of Intense Rainfall and Extreme Dry Events on the Peat Slope ... 6

3. DESK STUDY ... 7

3.1 Desk Study ... 7

3.2 Soils, Subsoil & Bedrock ... 7

3.3 Previous Failures ... 8

3.4 Ground Conditions along Grid Connection ... 8

4. FINDINGS OF SITE RECONNAISSANCE ... 9

4.1 Site Reconnaissance ... 9

4.2 Findings of Site Reconnaissance ... 9

5. SITE GROUND CONDITIONS ... 13

5.1 Soils & Subsoils ... 13

5.2 Bedrock ... 13

6. PEAT DEPTHS, STRENGTH & SLOPE AT PROPOSED INFRASTRUCTURE LOCATIONS ... 14

6.1 Peat Depth ... 14

6.2 Peat Strength ... 14

6.3 Slope Angle ... 14

6.4 Summary of Findings ... 14

7. PEAT STABILITY ASSESSMENTS ... 17

7.1 Methodology for Peat Stability Assessment ... 17

7.2 Analysis to Determine Factor of Safety (Deterministic Approach) 19
7.3 Results of Analysis 21
7.3.1 Undrained Analysis for the Peat 21
7.3.2 Drained Analysis for the Peat 23
8. PEAT STABILITY RISK ASSESSMENT 24
8.1 Summary of Risk Assessment Results 24
9. SUMMARY AND RECOMMENDATIONS 26
9.1 Summary 26
9.2 Recommendations 26
10. REFERENCES 28

LIST OF APPENDICES

Appendix A: Peat Stability Risk Register
Appendix B: Calculated FoS for Peat Slopes on Site
Appendix C: Methodology for Peat Stability Risk Assessment

LIST OF FIGURES

Figure 2.1: Methodology for Peat Stability Assessment 3
Figure 2.2: Peat Slope Showing Balance of Forces to Maintain Stability 5
Figure 4.1: Peat Depth Contour Plan 11
Figure 4.2: Construction Buffer Zone Plan 12
Figure 6.1: Undrained Shear Strength (c_u) Profile for Peat with Depth 16
Figure 7.1: Factor of Safety Plan – Short Term Critical Condition (Undrained) 22

LIST OF TABLES

Table 6.1: Peat Depth & Slope Angle at Proposed Infrastructure Locations 15
Table 7.1: List of Effective Cohesion and Friction Angle Values for Peat 18
Table 7.2: Factor of Safety Limits for Slopes 19
Table 7.3: Factor of Safety Results (Undrained Condition) 21
Table 7.4: Factor of Safety Results (Drained Conditions) 23
Table 8.1: Risk Rating Legend 24
Table 8.2: Summary of Peat Stability Risk Register 25

1. NON-TECHNCIAL SUMMARY

Fehily Timoney and Company (FT) was engaged by Bracklyn Wind Farm Ltd. to undertake a geotechnical and peat stability assessment of the proposed Bracklyn Wind Farm site. In accordance with planning guidelines compiled by the Department of the Environment, Heritage and Local Government (DoEHLG), where peat is present on a proposed wind farm development, a peat stability assessment is required.

A walkover including intrusive peat depth probing, desk study, stability analysis and risk assessment was carried out to assess the susceptibility of the site to peat failure following the principles in Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments (PLHRAG, 2nd Edition, 2017).

The findings show that the proposed development has an acceptable margin of safety and is suitable for the proposed wind farm development. Based on the findings, recommendations and control measures for construction work in peat lands are suggested to ensure that all works adhere to an acceptable standard of safety.

The proposed development comprises 9 no. wind turbines and associated infrastructure. The site comprises relatively flat/gently undulating agricultural land with areas of peat bog to the north and east. Up to 2km of existing tracks are present on the site and have been in operation for a number of years.

Slope inclinations at the main infrastructure locations range from 1 to 3 degrees. The relatively flat topography/nature of the terrain on site reflects the low risk of peat failure. Ground conditions comprise mainly of peaty topsoil or peat overlying clay or silt overlying bedrock.

Peat depth recorded during the site walkovers from over 50 probes ranged from 0 to 2.5m with an average peat depth of 0.6m. 86% of the probes recorded peat depths of less than 1.0m with 95% of peat depth probes recorded peat depths of less than 2.0m. A number of localised readings recorded peat depths from 2.0 to 2.5m (T10).

The purpose of the stability analysis was to determine the stability i.e. Factor of Safety (FoS), of the peat slopes. The FoS provides a direct measure of the degree of stability of a peat slope. A FoS of less than 1.0 indicates that a slope is unstable; a FoS of greater than 1.0 indicates a stable slope. An acceptable FoS for slopes is generally taken as a minimum of 1.3. The stability analysis for this project, which analysed the turbine locations, access roads and substation, resulted in FoS above the minimum acceptable value of 1.3 and hence the site has a satisfactory margin of safety.

The risk assessment uses the results of the stability analysis in combination with qualitative factors, which cannot be reasonably included in a stability calculation but nevertheless may affect the occurrence of peat instability, to assess the risk of peat failure at the site. The results of the risk assessment are given in Appendix A. A construction buffer zone plan based on qualitative factors identified during the site walkover is included as Figure 4.2.

In summary, the proposed development site has an acceptable margin of safety and is considered to be at **low** risk of peat failure.

2. INTRODUCTION

2.1 Fehily Timoney and Company

Fehily Timoney and Company (FT) is an Irish engineering, environmental science and planning consultancy with offices in Cork, Dublin and Carlow. The practice was established in 1990 and currently has about 70 members of staff, including engineers, scientists, planners and technical support staff. FT deliver projects in Ireland and internationally in our core competency areas of Waste Management, Environment and Energy, Civils Infrastructure, Planning and GIS and Data Management.

2.2 Project Description

FT was engaged in March 2020 by Bracklyn Wind Farm Ltd to undertake a geotechnical & peat stability assessment of the proposed Bracklyn Wind Farm site in County Westmeath.

The proposed Bracklyn Wind Farm is located approximately 5km south of Delvin, Co. Westmeath.

The Bracklyn Wind Farm site, which comprises agricultural land, forestry and an area of cutover raised peat, extends to an approximate area of 2.75km^2. The site is located in the east of Co. Westmeath. The surrounding landscape comprises gently undulating topography with land-use comprising forestry, agricultural land and cutaway peatland.

The development comprises the following:

(1) 9 no. wind turbines with a overall blade tip height of up to 185m and all associated hard-standing areas

(2) 1 no. permanent meteorological mast up to 104m in height

(3) Provision of new site access tracks and associated drainage

(4) Temporary construction compound

(5) All works associated with the connection of the proposed wind farm to the national electricity grid, including the construction of an electricity substation

(6) New access junctions, improvements and temporary modifications to existing public road infrastructure to facilitate delivery of abnormal loads and construction access

(7) All associated site development works

2.3 Peat Stability Assessment Methodology

FT undertook the assessment following the principles in Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments, 2nd Edition (PLHRAG, 2017). The Peat Landslide Hazard and Risk Assessment Guide (PLHRAG) is used in this report as it provides best practice methods to identify, mitigate and manage peat slide hazards and associated risks in respect of consent applications for electricity generation projects.

The best practice guide was produced following peat failures in the Shetland Islands, Scotland in September 2003 but more pertinently following the peat failure in October 2003, during the construction of a wind farm at Derrybrien, County Galway, Ireland.

The geotechnical and peat stability assessment at the site included the following activities:

(1) Desk study

(2) Site reconnaissance including shear strength and peat depth measurements

(3) Peat stability assessment of the peat slopes on site using a deterministic and qualitative approach

(4) Peat contour depth plan – compiled based on the peat depth probes and trial pits carried out across the site by FT and Hydro Environmental Services (HES)

(5) Factor of safety plan – compiled for the short-term critical condition (undrained) for points analysed along the proposed infrastructure envelope on site

(6) Construction buffer zone plan – identifies areas with an elevated or higher construction risk where mitigation/control measures will need to be implemented during construction to minimise the potential risks and ensure they are kept within an acceptable range

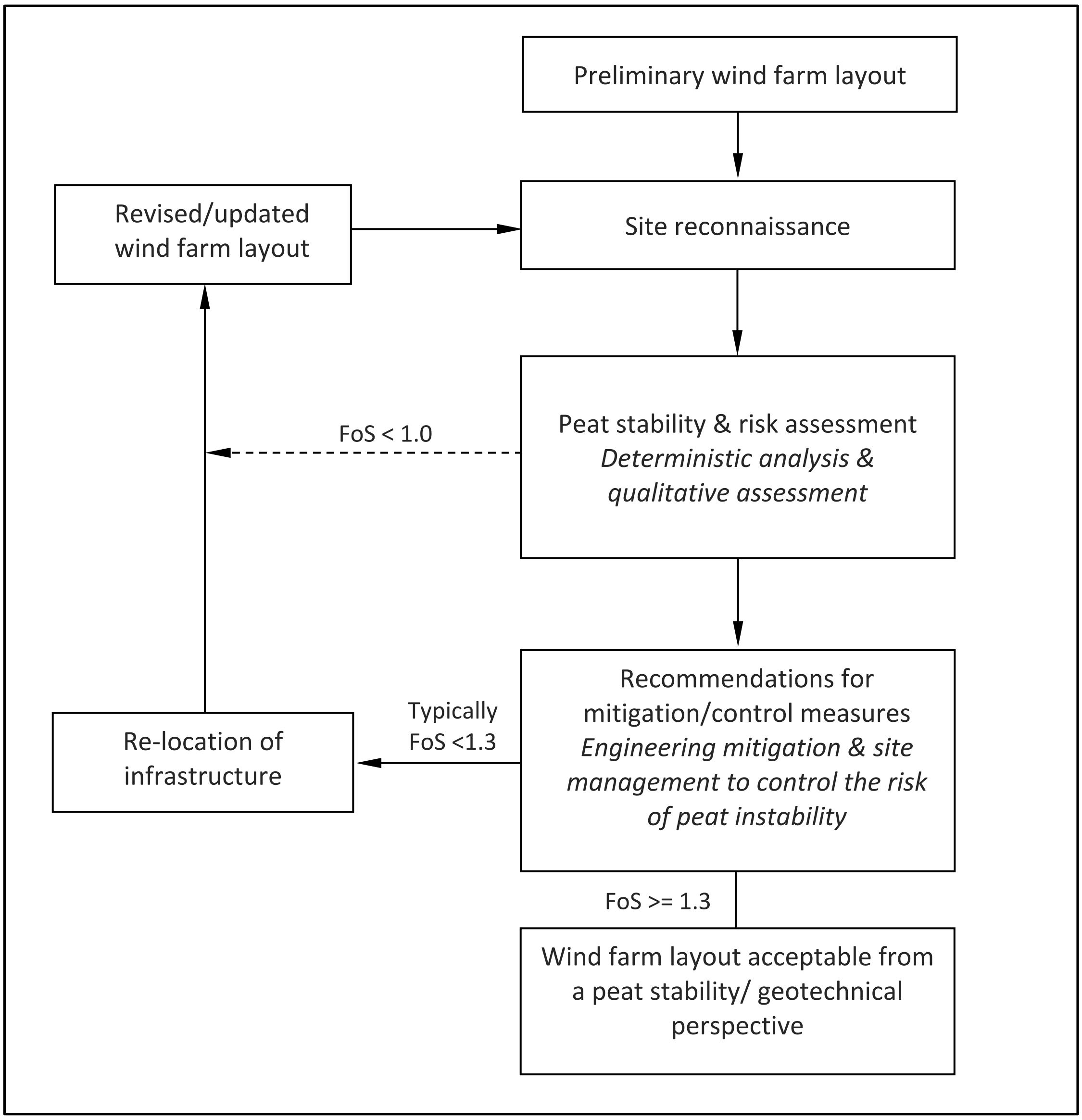
(7) A risk register was compiled to assess the potential design/construction risks at the infrastructure locations and determine adequate mitigation/control measures for each location to minimise the potential risks and ensure they are kept within an acceptable range, where necessary

(8) Preliminary assessment of foundation type for turbines

(9) Commentary of founding details for other infrastructure elements such as access roads, crane hardstands, substation & construction compound platforms and met mast foundation

A flow diagram showing the general methodology for peat stability assessment is shown in Figure 2.1. The methodology illustrates the optimisation of the wind farm layout based on the findings from the site reconnaissance and stability analysis and subsequent feedback.

Figure 2.1: Methodology for Peat Stability Assessment



2.4 Peat Failure Definition

Peat failure in this report refers to a significant mass movement of a body of peat that would have an adverse impact on the proposed development and the surrounding environment. Peat failure excludes localised movement of peat that would occur below an access road, creep movement or erosion type events.

The potential for peat failure at this site is examined with respect to construction works and associated activity.

2.5 Main Approaches to Assessing Peat Stability

The main approaches to assessing peat stability for wind farm developments include the following:

(1) Geomorphological

(2) Qualitative (judgement)

(3) Index/Probabilistic (probability)

(4) Deterministic (factor of safety)

Approaches (1) to (3) listed above are considered subjective and do not provide a definitive indication of stability; in addition, a high level of judgement/experience is required which makes it difficult to relate the findings to real conditions. FT apply a more objective approach, the deterministic approach (as discussed in Section 2.6).

As part of FT's deterministic approach, a qualitative risk assessment is also carried out taking into account qualitative factors, which cannot necessarily be quantified, such as the presence of mechanically cut peat, quaking peat, bog pools, sub peat water flow, slope characteristics and numerous other factors. The qualitative factors used in the risk assessment are compiled based on FT's experience of assessments and construction in peat land sites and peat failures throughout Ireland and the UK. This approach follows the guidelines for geotechnical risk management as given in Clayton (2001), as referenced in the best practice for Peat Landslide Hazard and Risk Assessment Guide (PLHRAG, 2017), and takes into account the approach of MacCulloch (2005).

The risk assessment uses the results of the deterministic approach in combination with qualitative factors, which cannot be reasonably included in a stability calculation but nevertheless may affect the occurrence of peat instability to assess the risk of instability on a peat land site.

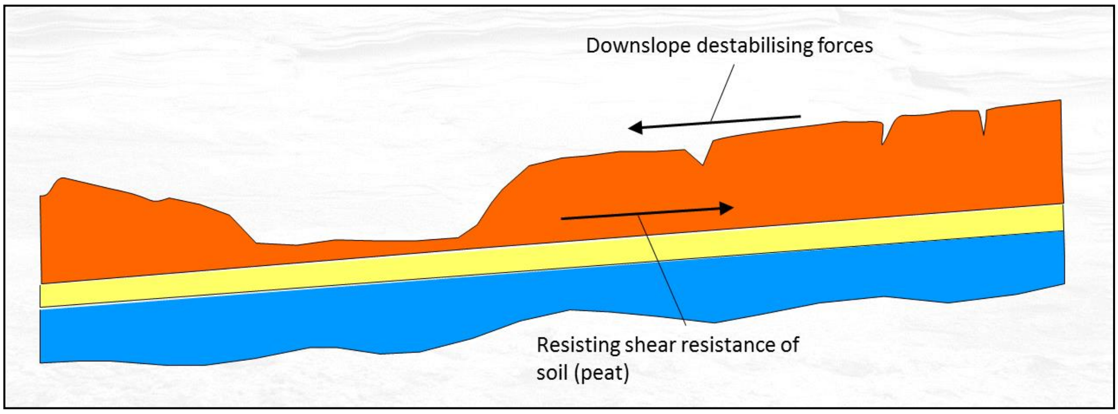
2.6 Peat Stability Assessment – Deterministic Approach

The peat stability assessment is carried out across a wide area to determine the stability of peat slopes and to identify areas of peatland that are suitable for development; this allows the layout of infrastructure on a particular wind farm site to be optimised. The assessment provides a numerical value (factor of safety) of the stability of individual parcels of peatland. The findings of the assessment discriminate between areas of stable and unstable peat, and areas of marginal stability where restrictions may apply. This allows for the identification of the most suitable locations for turbines, access roads and infrastructure.

A deterministic assessment requires geotechnical information and site characteristics which are obtained from desk study and site walkover, e.g. properties of peat/soil/rock, slope geometry, depth of peat, underlying strata, groundwater, etc. An adverse combination of the factors listed above could potentially result in instability. Using the information above, a factor of safety is calculated for the stability of individual parcels of peatland on a site (as discussed in Section 7).

The factor of safety is a measure of the stability of a particular slope. For any slope, the degree of stability depends on the balance of forces between the weight of the soil/peat working downslope (destabilising force) and the inherent strength of the peat/soil (shear resistance) to resist the downslope weight, see Figure 2.2.

Figure 2.2: Peat Slope Showing Balance of Forces to Maintain Stability



The factor of safety provides a direct measure of the degree of stability of a slope and is the ratio of the shear resistance over the downslope destabilising force. Provided the available shear resistance is greater than the downslope destabilising force then the factor of safety will be greater than 1.0 and the slope will remain stable. If the factor of safety is less than 1.0 the slope is unstable and liable to fail. The acceptable range for factor of safety is typically from 1.3 to 1.4.

2.7 Applicability of the Factor of Safety (Deterministic) Approach for Peat Slopes

The factor of safety approach is a standard engineering approach in assessing slopes which is applied to many engineering materials, such as peat, soil, rock, etc.

The factor of safety approach is included in the Peat Landslide Hazard and Risk Assessments Best Practice Guide for Proposed Electricity Generation Developments (PLHRAG, 2017); see Section 5.3.1 of the guide. This guide provides best practice methods to identify, mitigate and manage peat slide hazards and associated risks in respect of consent applications for electricity generation projects.

Furthermore, the best practice guide notes that the results from the factor of safety approach 'has provided the most informative results' with respect to analysing peat stability (Section 5.3.1 of the guide).

The factor of safety approach in this report includes undrained (short-term stability) and drained (long-term stability) analyses. The undrained condition is the critical condition for the development. The purpose of the drained analysis is to identify the relative susceptibility of rainfall-induced failures at the site.

Notwithstanding the above, the stability analysis used by FT in this report also includes qualitative factors to determine the potential for peat stability i.e. the analysis used does not solely rely on the factor of safety approach.

The deterministic analysis is considered an acceptable engineering design approach. This concurs with the best practice guide referenced above.

2.8 Assessment of Intense Rainfall and Extreme Dry Events on the Peat Slope

The deterministic approach carried out by FT examines intense rainfall and extreme dry events. The deterministic approach includes and undrained (short-term stability) and drained (long-term stability) analysis to assess the factor of safety for the peat slopes against a peat failure.

The drained loading condition applies in the long-term. This condition examines the effect of the change in groundwater level as a result of rainfall on the existing stability of the natural peat slopes. For the drained analysis the level of the water table above the failure surface is required to calculate the factor of safety for the peat slope.

In order to represent varying water levels within the peat slopes, a sensitivity analysis is carried out which assesses varying water level in the peat slopes i.e. water levels ranging from 0 to 100% of the peat depth is conducted, where 0% equates to the peat been completely dry and 100% equates to the peat being fully saturated.

By carrying out such a sensitivity analysis with varying water level in the peat slopes, the effects of intense rainfall and extreme dry events are considered and analysed. The results of which are presented in Section 7 of this report.

3. DESK STUDY

3.1 Desk Study

The main relevant sources of interest with respect to the site include:

- Geological plans and Geological Survey of Ireland database
- Ordnance survey plans
- Literature review of peat failures

The Geological Survey of Ireland (GSI, 1999) geological plans for the site were used to verify the soil and bedrock conditions.

The Ordnance Survey plans were reviewed to determine if any notable features or areas of particular interest (from a geotechnical point of view) are present on the site.

The desk study also includes a review of both published literature and GSI online dataset viewer (GSI, 2020) on peat failures/landslides in the vicinity of the site.

3.2 Soils, Subsoil & Bedrock

A review of the Geological Survey of Ireland online database and published documents from GSI namely sheet 13 Geology of Meath was carried out.

The GSI subsoils maps indicates that the site is underlain by a combination of cutover bog and till derived from limestone.

In relation to bedrock, the site location and surrounding area is underlain by the Walsortian Limestone (a Dinantian Impure Limestone), the Tobercolleen Formation and the Lucan Formation. The Walsortian Limestone is described as a massive, unbedded lime-mudstone. The Tobercolleen Formation is described as a calcareous shale, limestone conglomerate. The Lucan Formation is described as a dark limestone and shale.

There is one mapped fault running across the proposed wind farm site, which has a southeast to northwest trend, while the proposed underground electricity line (grid connection) traverses a further fault line.

No karst features were identified in the survey area. The closest recorded karst feature is a spring noted around 5km to the west of the site.

No geological heritage sites are noted within the site development. The closest feature is approximately 8km west of the proposed site location at Ballycor. This feature is described as Ballycor Mushroom Rocks, which represent an exposure of undercut limestone bedrock exposures.

3.3 Previous Failures

There are no recorded peat failures within the proposed development site (GSI, 2020). The nearest recorded peat failure is located some 16km northeast of the study area at Girley Bog. No information is available on the size of this failure

The landslide susceptibility the site was classified by the GSI (2020) as low susceptibility, which is expected given the relatively flat/gently undulating terrain present.

The presence, or otherwise, of relict peat failures or clustering of relict failures within an area is an indicator that particular site conditions exist that pre-dispose a site to failure or not as the case may be. Hence based on the historical data reviewed and the terrain and ground conditions present on site it can be concluded that site conditions in the area of the proposed development have a limited potential of peat failure.

3.4 Ground Conditions along Grid Connection

The proposed wind farm will connect to the national electricity network via:

- An underground cable (c.6.3 km in length) running from the proposed 110 kV substation, located within the proposed wind farm site, to the townland of Coolronan, Co. Meath where it will connect to the existing Corduff-Mullingar 110kV overhead electricity line. The proposed underground cable will be located on private lands and within the public road corridor.

No peat stability or geotechnical issues are envisaged as a result of the proposed grid connection works.

4. FINDINGS OF SITE RECONNAISSANCE

4.1 Site Reconnaissance

As part of the assessment of potential peat failure at the proposed site, FT carried out a site reconnaissance in conjunction with the desk study review described in Section 3. This comprised walkover inspections of the site with recording of salient geomorphological features with respect to the wind farm development which included peat depth and preliminary assessment of peat strength. General photographs of the site are included at the end of the main text.

The following salient geomorphological features were considered:

- Active, incipient or relict instability (where present) within the peat deposits
- Presence of shallow valley or drainage line
- Wet areas
- Any change in vegetation
- Peat depth
- Slope inclination and break in slope

The survey covered the proposed turbine locations and associated infrastructure.

The method adopted for carrying out the site reconnaissance relied on experienced practitioners carrying out a visual assessment of the site supplemented with measurement of slope inclinations.

4.2 Findings of Site Reconnaissance

The site reconnaissance comprised a walkover inspection of the site during September 2020. Weather conditions for the site visit were mainly dry.

The findings from the site walkover have been used to optimise the layout of the infrastructure on site.

The main findings of the site walkover of the wind farm site are as follows:

(1) The site is predominantly agricultural land, comprising flat terrain. Areas of peat are located in the north and east of the site and these areas are largely afforested.

(2) A series of peat depth probes were carried out on site. Peat depths recorded across the site ranged from 0 to 2.5m with an average depth of 0.6m (Figure 4-1). Approximately 95 percent of peat depth probes recorded peat depths of less than 2.0m. A number of localised readings were recorded where peat depths were 2.0 to 2.5m.

(3) The peat depths recorded at the turbine locations varied from 0.2 to 2.5m with an average depth of 1.2m.

(4) With respect to the new proposed access tracks, peat depths are typically less than 1.0m with localised depths of up to 2.5m recorded.

(5) Access tracks for the wind farm comprise the upgrade of existing agricultural/forestry tracks and the construction of new tracks. The construction of new tracks will be carried out using an excavate &

replace construction technique which involves the removal and replacement of peat or soft ground where encountered.

(6) Slope angles at the turbine locations ranged from 1 to 3 degrees. These slope angle readings were obtained using a combination of readings taken during the site reconnaissance by FT using handheld equipment, such as the Silva Clino Master which has an accuracy of +/- 0.25 degrees and from contour survey plans for the site.

(7) The slope angle quoted typically reflects the slope within the footprint of each infrastructure location. The flat topography/nature of the terrain on site highlights the low risk of peat failure.

(8) No evidence of past failures or any significant signs of peat instability were noted on site.

(9) A summary of the site walkover findings for the wind farm are as follows:

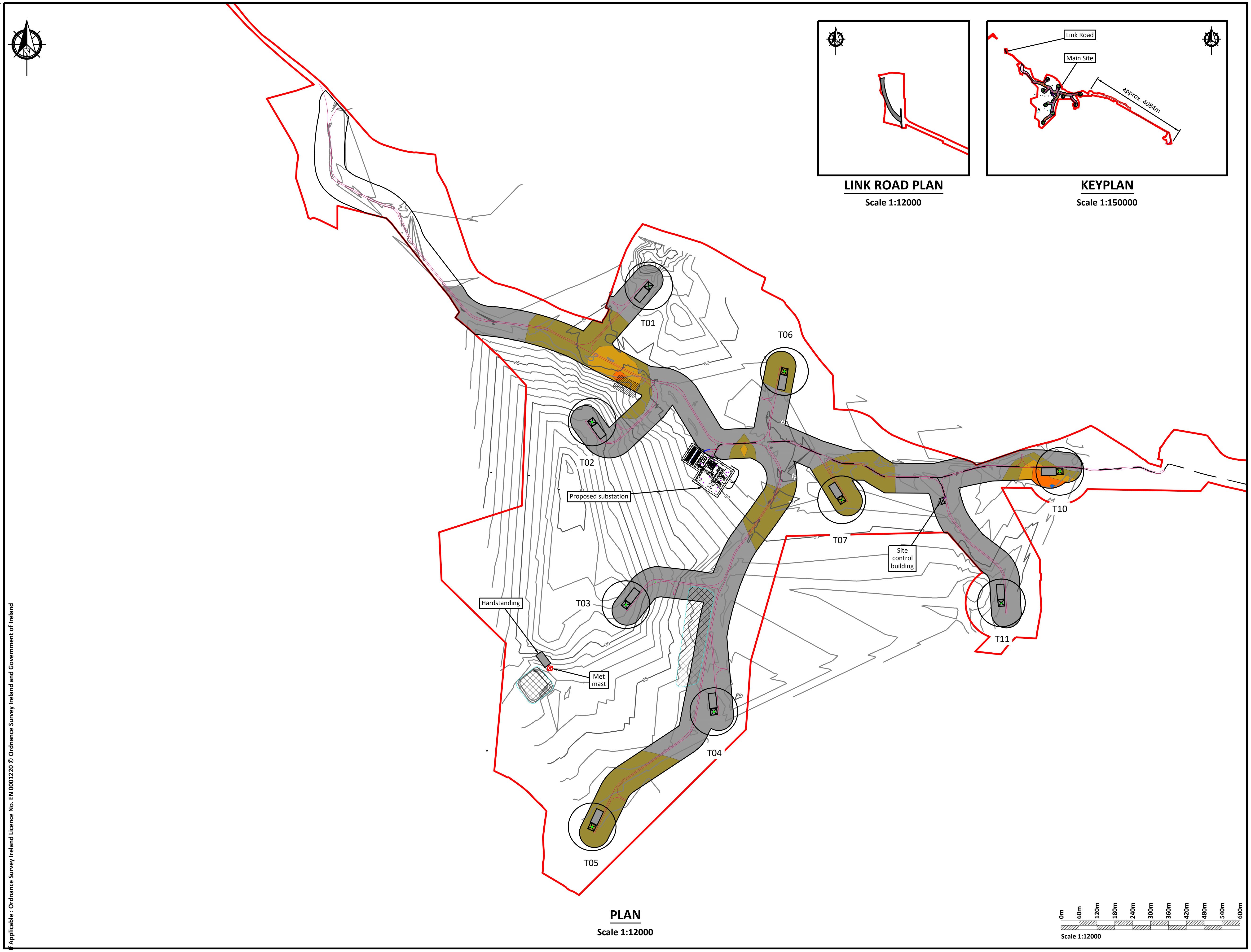
(a) The site comprises relatively flat terrain with localised areas of peat in the north and east of the site. Peat depths recorded across the site ranged from 0 to 2.5m with an average depth of 0.6m.

(b) A construction buffer zone plan has been produced for the site (Figure 4-2). This shows areas on the site where no development is advised and areas with an elevated or higher construction risk. The above identified buffer areas are based on qualitative factors identified during the walkover survey e.g. relatively deep peat, quaking peat, mechanically cut peat, recent peat landslide, etc.

(c) The results of the peat depth probing, shear strength testing of the peat and qualitative factors identified on site have been used in the stability and risk assessments, see Sections 6, 7 and 8 of this report for details.

(d) Based on the findings of the walkover survey, the proposed development is considered to have a low risk of peat failure.

In summary, based on the findings from the site reconnaissance, the proposed development would be considered to have a low risk of peat instability.



FEHILY TIMONEY Cork | Dublin | Carlow www.fehilytimoney.ie

Peat Depth Legend:

- ≥ 0 < 0.5
- ≥ 0.5 < 1
- ≥ 1 < 1.5
- ≥ 1.5 < 2
- ≥ 2 < 2.5

Legend:

- Turbine
- Deposition Area
- Site Compound
- New Internal Roads
- Cable Route
- Site Boundary
- Existing Ground Contours

Scale (@ A3)
1:12000

Date - 15.07.21

FIGURE 4.1 - PEAT DEPTH CONTOUR PLAN

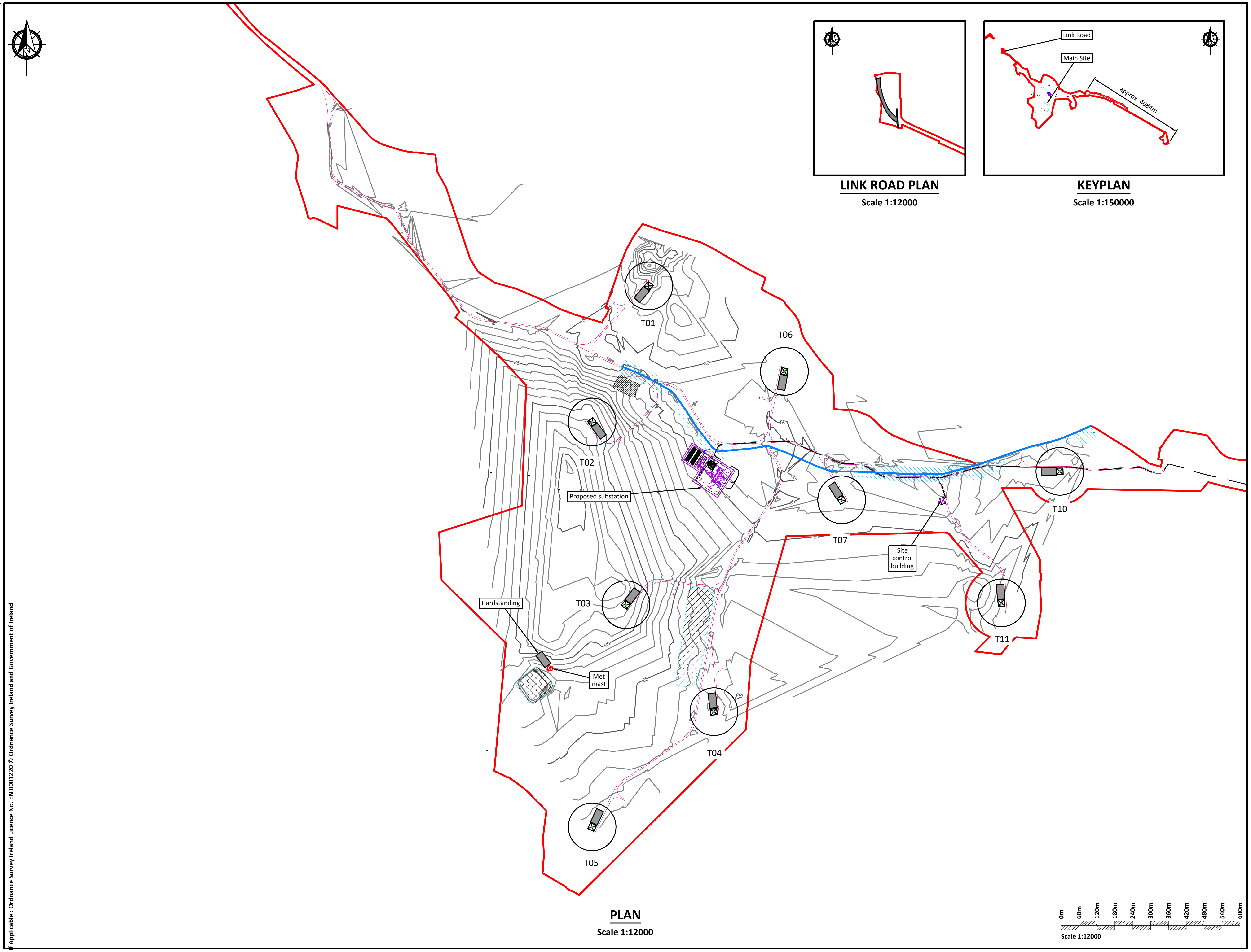
Drawn - POR

Checked - IH

Rev - F

O:\ACAD\2020\P20-215\P20-215-0600-0001

Thursday 15 July 2021



FEHILY TIMONEY
Cork | Dublin | Carlow
www.fehilytimoney.ie

Construction Buffer Zone Legend:

- 50m watercourse / drain buffer
- Watercourse

Legend:

- Turbine
- Deposition Area
- Site Compound
- New Internal Roads
- Cable Route
- Site Boundary
- Existing Ground Contours

Scale (@ A3)
1:12000

Date - 15.07.21

FIGURE 4.2 - CONSTRUCTION BUFFER ZONE PLAN

Drawn - POR
Checked - IH
Rev - E

O:\ACAD\2020\P20-215\P20-215-0600-0009

Thursday 15 July 2021

5. SITE GROUND CONDITIONS

5.1 Soils & Subsoils

A review of the GSI subsoils maps in Section 3 indicates that the site is underlain by a combination of cutover raised peat, localised gravel deposits and till derived from Limestones.

Based on the site walkover undertaken by FT and trial pits excavated by HES, the superficial deposits for the site were typically described as peaty topsoil or spongy brown/black fibrous and amorphous Peat overlying typically firm and stiff slightly gravelly Silt/Clay. Where peat was present on site, peat depths ranged from 0 to 2.5m with an average depth of 0.6m.

5.2 Bedrock

A review of the GSI bedrock maps in Section 3 indicates that the site location and surrounding area is underlain by the Walsortian Limestone (a Dinantian Impure Limestone), the Tobercolleen Formation and the Lucan Formation. The Walsortian Limestone is described as a massive, unbedded lime-mudstone. The Tobercolleen Formation is described as a calcareous shale, limestone conglomerate. The Lucan Formation is described as a dark limestone and shale.

There is one mapped fault running across the proposed wind farm site, which has a southeast to northwest trend, while the proposed underground electricity line (grid connection) traverses a further fault line.

No karst features were identified in the survey area. The closest recorded karst feature is a spring noted around 5km to the west of the site.

6. PEAT DEPTHS, STRENGTH & SLOPE AT PROPOSED INFRASTRUCTURE LOCATIONS

As part of the site walkover, peat depth, in-situ peat strength and slope angles were recorded at various locations across the site.

6.1 Peat Depth

Peat depth probes were carried out at/near to proposed turbine locations and access tracks and other main infrastructure elements. At turbine locations up to 5 probes were carried out around the turbine location, where accessible, and an average peat depth was calculated.

6.2 Peat Strength

The strength testing was carried out in-situ using a Geonor H-60 Hand-Field Vane Tester. From FT's experience, hand vanes give indicative results for in-situ strength of peat and would be considered best practice for the field assessment of peat strength.

6.3 Slope Angle

The slope angles at each of the main infrastructure locations were obtained using a combination of readings taken during the site reconnaissance by FT using handheld equipment, such as the Silva Clino Master and from contour survey plans for site.

The slope angle quoted typically reflects the slope within the footprint of each infrastructure location. It should be noted that slope angles derived from contour survey plans would be considered approximate, as such surveys are dependent on the density of survey data and do not always reflect local variations in ground topography. Slope angles recorded during the site reconnaissance by FT using handheld equipment would generally be deemed more accurate and representative of local topography.

6.4 Summary of Findings

Based on the peat depths recorded across the site by FT and HES, the peat varied in depth from 0 to 2.5m with an average depth of 0.6m. All peat depth probes carried out on site have been utilised to produce a peat depth contour plan for the site (Figure 4.1).

A summary of the peat depths at the proposed infrastructure locations is given in Table 6.1. The data presented in Table 6.1 is used in the peat stability assessment of the site.

Table 6.1: Peat Depth & Slope Angle at Proposed Infrastructure Locations

Turbine	Easting	Northing	Peat Depth Range (m) (1)	Average Peat Depth (m)	Slope Angle (°) (2)
T1	660970	759136			2
T2	660780	758679			2
T3	660893	758066			2
T4	661188	757707	0.2 – 0.3	0.25	2
T5	660780	757320	0.3 – 1.0	0.7	3
T6	661425	758848	0.5 – 1.0	0.7	1
T7	661617	758418	0.3 – 1.0	0.75	1
T10	662348	758513	0.8 – 2.5	1.8	1
T11	662152	758072			1
Substation	661172	758511	1.0	1.0	2
Met Mast	660639	757853			1

Note (1) Based on probe results from the site walkovers. The range of peat depths for the infrastructure locations are typically based on a 10m grid carried out around the infrastructure element, where accessible.

Note (2) The slope angles at each of the main infrastructure locations were obtained using a combination of readings taken during the site reconnaissance by FT using handheld equipment, such as the Silva Clino Master (which has an accuracy of +/- 0.25 degrees) and from contour survey plans for site. The slope angle quoted typically reflects the slope within the footprint of each infrastructure location.

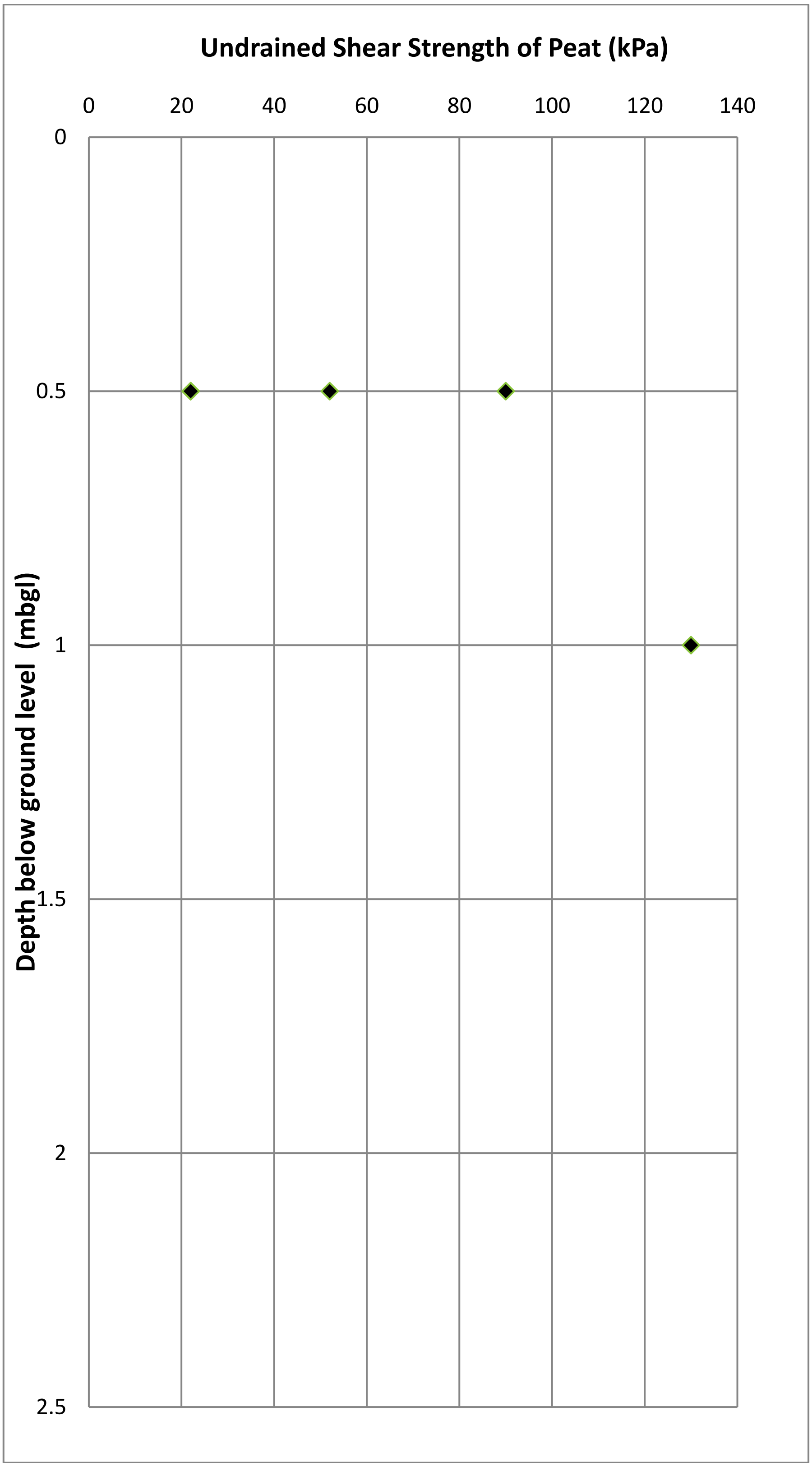
Note (3) The data presented in the Table above is used in the peat stability assessment of the site.

In addition to probing, in-situ shear vane testing was carried out as part of the ground investigation. Strength testing was carried out at selected locations across the site to provide representative coverage of indicative peat strengths. The results of the vane testing with depth are presented in Figure 6.1.

The hand vane results indicate undrained shear strengths in the range 22 to 130kPa, with an average value of about 60kPa. The strengths recorded would be typical of a thin, well drained peat as is present on the proposed development site.

Peat strength at sites of known peat failures (assuming undrained loading failure) are generally very low, for example the undrained shear strength at the Derrybrien failure (AGEC, 2004) as derived from back-analysis, was estimated at 2.5kPa. The recorded undrained strength at the proposed development site is significantly greater than the lower bound values for Derrybrien indicating that there is no close correlation to the peat conditions at the Derrybrien site and that there is significantly less likelihood of failure on the Bracklyn Wind Farm site.

Figure 6.1: Undrained Shear Strength (c_u) Profile for Peat with Depth



7. PEAT STABILITY ASSESSMENTS

The peat stability assessment includes an assessment of the stability of the natural peat slopes for individual parcels across the site including at the turbine locations and along the proposed access tracks. The assessment also analyses the stability of the natural peat slopes with a surcharge loading of 10kPa, equivalent to placing 1m of stockpiled peat on the surface of the peat slope.

7.1 Methodology for Peat Stability Assessment

Stability of a peat slope is dependent on several factors working in combination. The main factors that influence peat stability are slope angle, shear strength of peat, depth of peat, pore water pressure and loading conditions.

An adverse combination of factors could potentially result in peat sliding. An adverse condition of one of the above-mentioned factors alone is unlikely to result in peat failure. The infinite slope model (Skempton and DeLory, 1957) is used to combine these factors to determine a factor of safety for peat sliding. This model is based on a translational slide, which is a reasonable representation of the dominant mode of movement for peat failures.

To assess the factor of safety for a peat slide, an undrained (short-term stability) and drained (long-term stability) analysis has been undertaken to determine the stability of the peat slopes on site.

1. The undrained loading condition applies in the short-term during construction and until construction induced pore water pressures dissipate.

2. The drained loading condition applies in the long-term. The condition examines the effect of the change in groundwater level as a result of rainfall on the existing stability of the natural peat slopes.

Undrained shear strength values (c_u) for peat are used for the total stress analysis. Based on the findings of the 2003 Derrybrien failure and other failures in peat, undrained loading during construction was found to be the critical failure mechanism.

A drained analysis requires effective cohesion (c’) and effective friction angle (ø’) values for the calculations. These values can be difficult to obtain because of disturbance experienced when sampling peat and the difficulties in interpreting test results due to the excessive strain induced within the peat. To determine suitable drained strength values a review of published information on peat was carried out. Table 7.1 shows a summary of the published information on peat together with drained strength values.

From Table 7.1 the values for c’ ranged from 1.1 to 8.74kPa and ø’ ranged from 21.6 to 43°. The average c’ and ø’ values are 4.5kPa and 30° respectively. Based on the above, it was considered to adopt a conservative approach and to use design values below the averages. For design the following general drained strength values have been used for the site:

c’ = 4kPa
ø’ = 25°

Table 7.1: List of Effective Cohesion and Friction Angle Values for Peat

Reference	Cohesion, c' (kPa)	Friction Angle, ø' (degs)	Testing Apparatus/ Comments
Hanrahan et al (1967)	5 to 7	36 to 43	From triaxial apparatus
Rowe and Mylleville (1996)	2.5	28	From simple shear apparatus
Landva (1980)	2 to 4	27.1 to 32.5	Mainly ring shear apparatus for normal stress greater than 13kPa
	5 to 6	-	At zero normal stress
Carling (1986)	6.5	0	-
Farrell and Hebib (1998)	0	38	From ring shear and shear box apparatus. Results are not considered representative.
	0.61	31	From direct simple shear (DSS) apparatus. Result considered too low therefore DSS not considered appropriate
Rowe, Maclean and Soderman (1984)	1.1	26	From simple shear apparatus
	3	27	From DSS apparatus
McGreever and Farrell (1988)	6	38	From triaxial apparatus using soil with 20% organic content
	6	31	From shear box apparatus using soil with 20% organic content
Hungr and Evans (1985)	3.3	-	Back-analysed from failure
Dykes and Kirk (2006)	3.2	30.4	Test within acrotelm
Dykes and Kirk (2006)	4	28.8	Test within catotelm
Warburton et al (2003)	5	23.9	Test in basal peat
Warburton et al (2003)	8.74	21.6	Test using fibrous peat
Hendry et al (2012)	0	31	Remoulded test specimen
Komatsu et al (2011)	8	34	Remoulded test specimen
Zwanenburg et al (2012)	2.3	32.3	From DSS apparatus
Den Haan & Grognet (2014)	-	37.4	From large DSS apparatus
O'Kelly & Zhang (2013)	0	28.9 to 30.3	Tests carried out on reconstituted, undisturbed and blended peat samples

7.2 Analysis to Determine Factor of Safety (Deterministic Approach)

The purpose of the analysis was to determine the Factor of Safety (FoS) of the peat slopes using infinite slope analysis. The analysis was carried out at the turbine locations, along the proposed access tracks and at various locations across the site.

The FoS provides a direct measure of the degree of stability of the slope. A FoS of less than unity indicates that a slope is unstable, a FoS of greater than unity indicates a stable slope.

The acceptable safe range for FoS typically ranges from 1.3 to 1.4. The previous code of practice for earthworks BS 6031:1981 (BSI, 1981), provided advice on design of earthworks slopes. It stated that for a first-time failure with a good standard of site investigation the design FoS should be greater than 1.3.

As a general guide, the FoS limits for peat slopes in this report are summarised in Table 7.2.

Table 7.2: Factor of Safety Limits for Slopes

Factor of Safety (FoS)	Degree of Stability
Less than 1.0	Unstable (red)
Between 1.0 and 1.3	Marginally stable (yellow)
1.3 or greater	Acceptable (green)

Eurocode 7 (EC7) (IS EN 1997-1:2005) now serves as the reference document and the basis for design geotechnical engineering works. The design philosophy used in EC7 applies partial factors to soil parameters, actions and resistances. Unlike the traditional approach, EC7 does not provide a direct measure of stability, since global Factors of Safety are not used.

As such, and in order to provide a direct measure of the level of safety on a site, EC7 partial factors have not been used in this stability assessment. The results are given in terms of FoS.

A lower bound undrained shear strength, c_u for the peat of 8kPa was selected for the assessment based on the c_u values recorded at the proposed development site. It should be noted that a c_u of 8kPa for the peat is considered a conservative value for the analysis and is not representative of all peat present across the site. In reality the peat has a higher undrained strength.

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

$$F = \frac{c_u}{\gamma z \sin\alpha \cos\alpha}$$

Where:

F = Factor of Safety

c_u = Undrained strength

γ = Bulk unit weight of material

z = Depth to failure plane assumed as depth of peat

α = Slope angle

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

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

Where:

F = Factor of Safety

c' = Effective cohesion

γ = Bulk unit weight of material

z = Depth to failure plane assumed as depth of peat

γ_w = Unit weight of water

h_w = Height of water table above failure plane

α = Slope angle

ϕ' = Effective 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 peat can be variable and can be recharged by rainfall, it is not feasible to establish its precise location throughout the site. Therefore, a sensitivity analysis using water level ranging between 0% and 100% of the peat depth was conducted, where 0% equates to the peat being completely dry and 100% equates to the peat been fully saturated.

The following general assumptions were used in the analysis of peat slopes at each location:

(1) Peat depths are based on the maximum peat depth recorded at each location from the walkover surveys.

(2) The slope angles used in the peat stability assessment were obtained using of readings taken during the site reconnaissance by FT using handheld equipment.

(3) Slope angle at base of sliding assumed to be parallel to ground surface.

(4) A lower bound undrained shear strength, c_u for the peat of 8kPa was selected for the assessment. The lowest recorded value at the proposed development site during the walkover was 22kPa. It should be noted that a c_u of 8kPa for the peat is considered a conservative value for the analysis and is not representative of all peat present across the site. In reality, the peat at the proposed development site has a significantly higher undrained strength as a result of the extensive drainage & extraction works which have been carried out on site.

For the stability analysis two load conditions were examined, namely

Condition (1): no surcharge loading

Condition (2): surcharge of 10 kPa, equivalent to 1m of stockpiled peat assumed as a worst case.

7.3 Results of Analysis

7.3.1 Undrained Analysis for the Peat

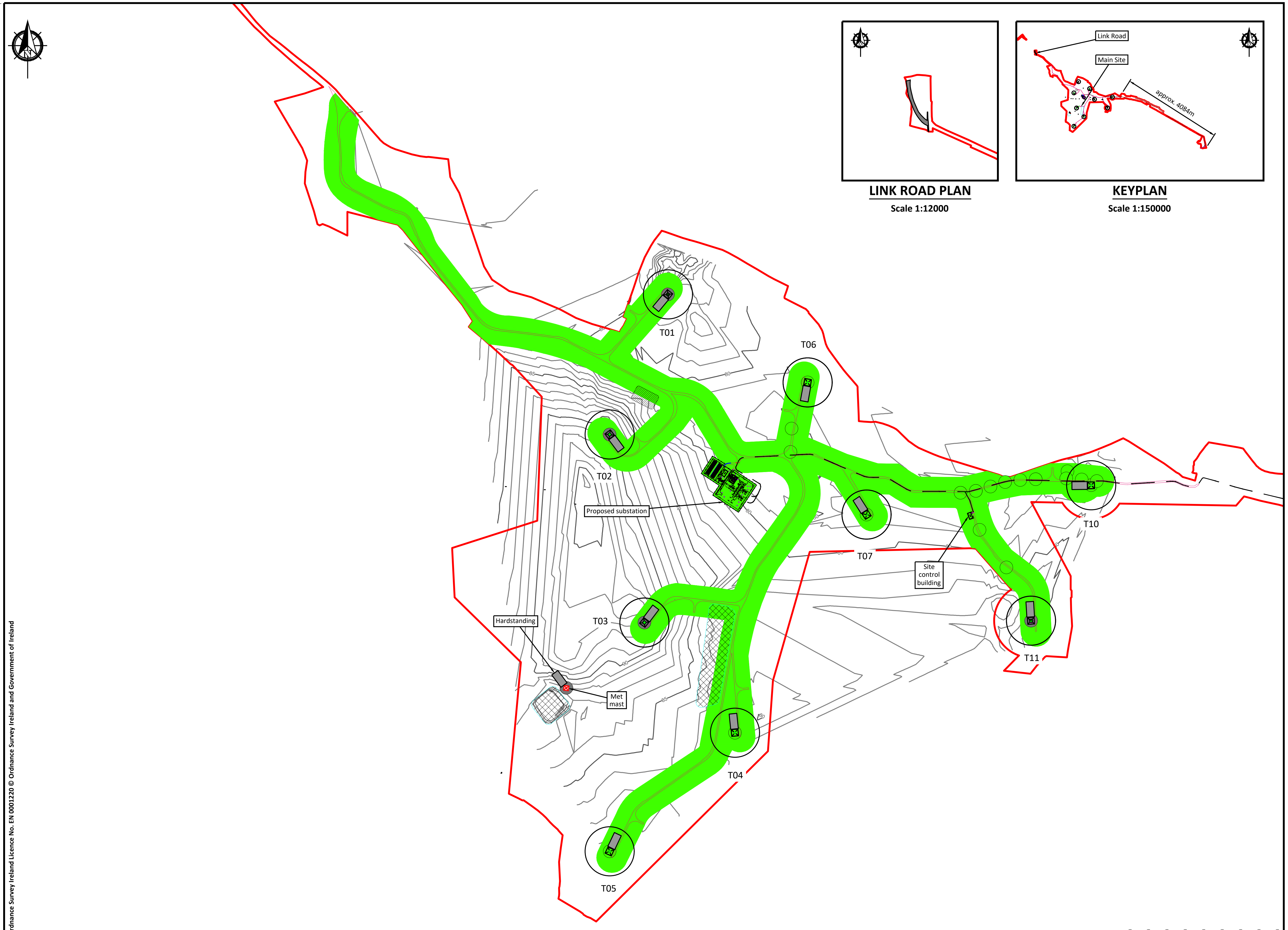
The results of the undrained analysis for the natural peat slopes are presented in Appendix B and the results of the undrained analysis for the most critical load case (load condition 2) are shown on Figure 7.1. The undrained analysis for load condition 2 is considered the most critical load case as most peat failures occur in the short term upon loading of the peat surface. The results from the main infrastructure locations are summarised in Table 7.3.

The calculated FoS for load condition 1 is in excess of 1.30 for each of the locations analysed with a range of FoS of 15.31 to in excess of 10, indicating a low risk of peat instability.

The calculated FoS for load condition 2 is in excess of 1.30 for each of the locations analysed with a range of FoS of 7.65 to in excess of 10, indicating a low risk of peat instability.

Table 7.3: Factor of Safety Results (Undrained Condition)

Turbine No./Waypoint	Easting	Northing	Factor of Safety for Load Condition	
			Condition (1)	Condition (2)
T1	No peat encountered			
T2	No peat encountered			
T3	No peat encountered			
T4	661188	757707	**76.46**	**17.64**
T5	660780	757320	**15.31**	**7.65**
T6	661425	758848	**45.85**	**22.92**
T7	661617	758418	**45.85**	**22.92**
T10	662348	758513	**18.34**	**13.1**
T11	No peat encountered			
Substation	661172	758511	**22.94**	**11.47**
Met Mast	No peat encountered			



PLAN

Scale 1:12000

LINK ROAD PLAN

Scale 1:12000

KEYPLAN

Scale 1:150000

FEHILY TIMONEY Cork | Dublin | Carlow www.fehilytimoney.ie

Factor of Safety Legend:

- 0 < 1.0
- ≥ 1.0 < 1.3
- ≥ 1.3
- No Peat Recorded At This Location

Increasing Stability

Legend:

- Turbine
- Deposition Area
- Site Compound
- New Internal Roads
- Cable Route
- Site Boundary
- Existing Ground Contours

Scale (@ A3)
1:12000

Date - 15.07.21

FIGURE 7.1 - FACTOR OF SAFETY PLAN - SHORT TERM CRITICAL CONDITION (UNDRAINED)

Drawn - POR
Checked - IH
Rev - F

O:\ACAD\2020\P20-215\P20-215-0600-0002

Thursday 15 July 2021

7.3.2 Drained Analysis for the Peat

The results of the drained analysis for the peat are presented in Appendix B. The results from the main infrastructure locations are summarised in Table 7.4. As stated previously, the drained loading condition examines the effect of rainfall and water on the existing stability of the natural peat slopes.

The calculated FoS for load condition 1 is in excess of 1.30 for each of the locations analysed with a range of FoS of 7.65 to in excess of 10, indicating a low risk of peat instability.

The calculated FoS for load condition 2 is in excess of 1.30 for each of the locations analysed with a range of FoS of 8.28 to in excess of 10, indicating a low risk of peat instability.

Table 7.4: Factor of Safety Results (Drained Conditions)

Turbine No./Waypoint	Easting	Northing	Factor of Safety for Load Condition	
			Condition (1)	Condition (2)
T1	No peat encountered			
T2	No peat encountered			
T3	No peat encountered			
T4	661188	757707	38.23	19.09
T5	660780	757320	7.65	8.28
T6	661425	758848	22.92	24.82
T7	661617	758418	22.92	24.82
T10	662348	758513	9.17	14.18
T11	No peat encountered			
Substation	661172	758511	11.47	12.41
Met Mast	No peat encountered			

8. PEAT STABILITY RISK ASSESSMENT

A peat stability risk assessment was carried out for the main infrastructure elements at the wind farm. This approach takes into account guidelines for geotechnical/peat stability risk assessments as given in PLHRA (2017) and MacCulloch (2005).

The risk assessment uses the results of the stability analysis (deterministic approach) in combination with qualitative factors, which cannot be reasonably included in a stability calculation but nevertheless may affect the occurrence of peat instability, to assess the risk for each infrastructure element.

For each of the main infrastructure elements, a risk rating (product of probability and impact) is calculated and rated as shown in Table 8.1. Where a subsection is rated 'Medium' or 'High', control measures are required to reduce the risk to at least a 'Low' risk rating. Where a subsection is rated 'Low' or 'Negligible', only routine control measures are required.

Table 8.1: Risk Rating Legend

17 to 25	High: avoid works in area or significant control measures required
11 to 16	Medium: notable control measures required
5 to 10	Low: only routine control measures required
1 to 4	Negligible: none or only routine control measures required

A full methodology for the peat stability risk assessment is given in Appendix C.

8.1 Summary of Risk Assessment Results

The results of the peat stability risk assessment for potential peat failure at the main infrastructure elements is presented as a Geotechnical Risk Register in Appendix A and summarised in Table 8.2.

The risk rating for each infrastructure element at the proposed development is designated negligible following some mitigation/control measures being implemented. Sections of access tracks to the nearest infrastructure element will be subject to the same mitigation/control measures that apply to the nearest infrastructure element.

Details of the required mitigation/control measures can be found in the Geotechnical Risk Register for each infrastructure element (Appendix A).

Table 8.2: Summary of Peat Stability Risk Register

Infrastructure	Pre-Control Measure Implementation Risk Rating	Pre-Control Measure Implementation Risk Rating Category	Notable Control Measures Required	Post-Control Measure Implementation Risk Rating	Post-Control Measure Implementation Risk Rating Category
Turbine T1	No peat recorded at location				
Turbine T2	No peat recorded at location				
Turbine T3	No peat recorded at location				
Turbine T4	Negligible	1 to 4	No	Negligible	1 to 4
Turbine T5	Negligible	1 to 4	No	Negligible	1 to 4
Turbine T6	Negligible	1 to 4	No	Negligible	1 to 4
Turbine T7	Negligible	1 to 4	No	Negligible	1 to 4
Turbine T10	Low	5 to 10	No	Negligible	1 to 4
Turbine T11	No peat recorded at location				
Construction Compound	Negligible	1 to 4	No	Negligible	1 to 4
Substation	Negligible	1 to 4	No	Negligible	1 to 4
Met Mast	No peat recorded at location				

9. SUMMARY AND RECOMMENDATIONS

9.1 Summary

The following summary is given:

FT was engaged by Bracklyn Wind Farm Ltd. to undertake a geotechnical and peat stability assessment of the proposed Bracklyn Wind Farm site.

The findings of the peat assessment showed that the proposed development site has an acceptable margin of safety and is suitable for the proposed development. The findings include recommendations and control measures for construction work in peat lands to ensure that all works adhere to an acceptable standard of safety.

The site which comprises relatively flat/gently undulating terrain consists predominantly of agricultural land with peat present in the north and east of the site.

Peat thicknesses recorded during the site walkover ranged from 0 to 2.5m with an average depth of 0.6m. 86% of the probes recorded peat depths of less than 1.0m. 95% of peat depth probes recorded peat depths of less than 2.0m. A number of localised readings were recorded where peat depths from 2.0 to 2.5m.

Slope inclinations at the main infrastructure locations range from 1 to 3 degrees.

An analysis of peat sliding was carried out at the main infrastructure locations across site for both the undrained and drained conditions. The purpose of the analysis was to determine the Factor of Safety (FoS) of the peat slopes.

For the undrained condition, the calculated FoS for load conditions 1 and 2 for the locations analysed, showed that all locations have an acceptable FoS of greater than 1.3, indicating a low risk of peat failure. The undrained analysis would be considered the most critical condition for the peat slopes.

A drained analysis was also carried out, which examined the effect of in particular, rainfall on the existing stability of the natural peat slopes on site. For the drained condition, the calculated FoS for load conditions (1) & (2) for the locations analysed, showed that all locations have an acceptable FoS of greater than 1.3.

The peat stability risk assessment at each infrastructure location identified a number of mitigation/control measures to reduce the potential risk of peat failure. Sections of access tracks to the nearest infrastructure element should be subject to the same mitigation/control measures that apply to the nearest infrastructure element. See Appendix A for details of the required mitigation/control measures for each infrastructure element.

In summary, the findings of the peat assessment showed that the Bracklyn Wind Farm site has an acceptable margin of safety, is suitable for the proposed wind farm development and is considered to be at **low** risk of peat failure. The findings include recommendations and control measures for construction work in peat lands to ensure that all works adhere to an acceptable standard of safety.

9.2 Recommendations

The following recommendations are given.

Notwithstanding that the site has an acceptable margin of safety a number of mitigation/control measures are given to ensure that all works adhere to an acceptable standard of safety for work in areas of peat. Mitigation/control measures identified for each of the infrastructure elements in the risk assessment will be taken into account and implemented throughout design and construction works (Appendix A).

The proposed construction method for all the new proposed access tracks at the wind farm is excavate and replace type construction.

Recommendations and guidelines given in FT's report 'Peat Management Plan - Bracklyn Wind Farm' (FT 2021) will be taken into consideration during the design and construction stage of the proposed development.

To minimise the risk of construction activity causing potential peat instability, the Construction Method Statements (CMSs) for the project will take into account, but not be limited, to the recommendations above. This will ensure that best practice guidance regarding the management of peat stability will be inherent in the construction phase.

10. REFERENCES

Applied Ground Engineering Consultants (AGEC) (2004). Derrybrien Wind Farm Final Report on Landslide of October 2003.

Fehily Timoney and Company (FT) (2020). Peat & Spoil Management Plan - Bracklyn Wind Farm, (Rev 0). January 2021.

British Standards Institute (1981). BS 6031:1981 Code of practice for earthworks.

Bromhead, E.N. (1986). The Stability of Slopes.

Carling, P.A. (1986). Peat slides in Teesdale and Weardale, northern Pennines, July 1983: Description and failure mechanisms. Earth Surface Processes and Landforms, 11.

Clayton, C.R.I. (2001). Managing Geotechnical Risk. Institution of Civil Engineers, London.

Den Haan EJ and Grognet M (2014). A large direct simple shear device for the testing of peat at low stresses. Géotechnique Letters 4(4): 283–288, http://dx.doi.org/10.1680/geolett. 14.00033.

Dykes, A.P. and Kirk, K.J. (2006). Slope instability and mass movements in peat deposits. In Martini, I.P., Martinez Cortizas, A. and Chesworth, W. (Eds.) Peatlands: Evolution and Records of Environmental and Climatic Changes. Elsevier, Amsterdam.

Farrell, E.R. & Hebib, S. (1998). The determination of the geotechnical parameters of organic soils. Proceedings of International Symposium on problematic soils, IS-TOHOKU 98, Sendai, Japan.

Geological Survey of Ireland (2001). Sheet 13 Geology of Meath.

Geological Survey of Ireland (2006). Landslides in Ireland. Geological Survey of Ireland -Irish Landslides Group. July 2006.

Geological Survey of Ireland (2020). Online dataset public viewer, September 2020.

Hanrahan, E.T., Dunne, J.M. and Sodha, V.G. (1967). Shear strength of peat. Proc. Geot. Conf., Oslo, Vol. 1.

Hendrick, E. (1990). A Bog Flow at Bellacorrick Forest, Co. Mayo. Irish Forestry, Volume 47 (1): pp 32-44.

Hendry MT, Sharma JS, Martin CD and Barbour SL (2012). Effect of fibre content and structure on anisotropic elastic stiffness and shear strength of peat. Canadian Geotechnical Journal 49(4): 403–415, http://dx.doi.org/10.1139/t2012-003.

Hungr, O. and Evans, S.G. (1985). An example of a peat flow near Prince Rupert, British Columbia. Canadian Geotechnical Journal, 22.

Komatsu J, Oikawa H, Tsushima M and Igarashi M (2011). Ring shear test on peat. In Proceedings of the 21st International Offshore and Polar Engineering Conference, Maui, Hawaii, USA (Chung JS, Hong SY, Langen I and Prinsenberg SJ (eds)). International Society of Offshore and Polar Engineers, Cupertino, CA, USA, vol. 2, pp. 393–396.

Landva, A.O. (1980). Vane testing in peat. Canadian Geotechnical Journal, 17(1).

MacCulloch, F. (2005). Guidelines for the Risk Management of Peat Slips on the Construction of Low Volume/Low Cost Roads over Peat. RoadEx 11 Northern Periphery.

McGeever J. and Farrell E. (1988). The shear strength of an organic silt. Proc. 2nd Baltic Conf., 1, Tallin USSR.

O'Kelly BC and Zhang L (2013). Consolidated-drained triaxial compression testing of peat. Geotechnical Testing Journal 36(3): 310–321, http://dx.doi.org/10.1520/ GTJ20120053.

PLHRAG (2017). Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments. Prepared for Energy Consents Unit Scottish Government, 2nd Edition. Dated April 2017.

Skempton, A. W. and 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.

Warburton, J., Higgett, D. and Mills, A. (2003). Anatomy of a Pennine Peat Slide. Earth Surface Processes and Landforms.

Warburton, J., Holden, J. and Mills, A. J. (2003). Hydrological controls of surficial mass movements in peat. Earth-Science Reviews 67 (2004), pp. 139-156.

Zwanenburg C, Den Haan EJ, Kruse GAM and Koelewijn AR (2012). Failure of a trial embankment on peat in Booneschans, the Netherlands. Géotechnique 62(6): 479–490, http://dx.doi.org/10.1680/geot.9.P.094.

FEHILY TIMONEY

30 YEARS

CONSULTANTS IN ENGINEERING, ENVIRONMENTAL SCIENCE & PLANNING

APPENDIX A

Peat Stability Risk Registers

Bracklyn Wind Farm   - Peat Stability Risk Register (Rev 0)

Location:	**Turbine T1**

Grid Reference (Eastings, Northings):	**660970**	**759136**
Distance to Watercourse (m)	**50 - 100**	
Min & Max Measured Peat Depth (m):	**0.0**	
Control Required:	**No**	

		Pre-Control Measure Implementation						Post-Control Measure Implementation			
Ref.	Contributory/Qualitative Factors to Potential Peat Failure	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating	Control Required	Control measures to be implemented during construction	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating
1	FOS = n/a (u), n/a (d)	1	3	3	Negligible	No	See Below	1	3	3	Negligible
2	Evidence of sub peat water flow	0	3	0	Not Applicable	No		1	3	3	Negligible
3	Evidence of surface water flow	1	3	3	Negligible	No		1	3	3	Negligible
4	Evidence of previous failures/slips	0	3	0	Not Applicable	No		0	3	0	Not Applicable
5	Type of vegetation	1	3	3	Negligible	No		1	3	3	Negligible
6	General slope characteristics upslope/downslope from infrastructure location	2	3	6	Low	No		2	3	6	Low
7	Evidence of very soft/soft clay at base of peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
8	Evidence of mechanically cut peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
9	Evidence of quaking or buoyant peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
10	Evidence of bog pools	0	3	0	Not Applicable	No		0	3	0	Not Applicable
11	Other	0	3	0	Not Applicable	No		0	3	0	Not Applicable

	Control Measures to be Implemented Prior to/and During Construction for **Turbine T1**
	Not applicable - No peat recorded at proposed infrastructure location

Note
(1) FOS abbreviations are: u: FOS for undrained analysis, d: FOS for drained analysis.
(2) Probability assessed as per Table A and B of Appendix E.
(3) Impact based on distance of infrastructure element to nearest watercourse.

Bracklyn Wind Farm - Peat Stability Risk Register (Rev 0)

Location:	Turbine T2	
Grid Reference (Eastings, Northings):	660780	758679
Distance to Watercourse (m)	> 150	
Min & Max Measured Peat Depth (m):	0.0	
Control Required:	No	

		Pre-Control Measure Implementation						Post-Control Measure Implementation			
Ref.	Contributory/Qualitative Factors to Potential Peat Failure	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating	Control Required	Control measures to be implemented during construction	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating
1	FOS = n/a (u), n/a (d)	1	3	3	Negligible	No	See Below	1	3	3	Negligible
2	Evidence of sub peat water flow	1	3	3	Negligible	No		1	3	3	Negligible
3	Evidence of surface water flow	2	3	6	Low	No		2	3	6	Low
4	Evidence of previous failures/slips	0	3	0	Not Applicable	No		0	3	0	Not Applicable
5	Type of vegetation	2	3	6	Low	No		2	3	6	Low
6	General slope characteristics upslope/downslope from infrastructure location	2	3	6	Low	No		2	3	6	Low
7	Evidence of very soft/soft clay at base of peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
8	Evidence of mechanically cut peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
9	Evidence of quaking or buoyant peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
10	Evidence of bog pools	0	3	0	Not Applicable	No		0	3	0	Not Applicable
11	Other	0	3	0	Not Applicable	No		0	3	0	Not Applicable

	Control Measures to be Implemented Prior to/and During Construction for **Turbine T2**
	Not applicable - No peat recorded at proposed infrastructure location

Note
(1) FOS abbreviations are: u: FOS for undrained analysis, d: FOS for drained analysis.
(2) Probability assessed as per Table A and B of Appendix E.
(3) Impact based on distance of infrastructure element to nearest watercourse.

Bracklyn Wind Farm - Peat Stability Risk Register (Rev 0)

Location:	**Turbine T3**

Grid Reference (Eastings, Northings):	**660893**	**758066**
Distance to Watercourse (m)	**> 150**	
Min & Max Measured Peat Depth (m):	**0.0**	
Control Required:	**No**	

		Pre-Control Measure Implementation						Post-Control Measure Implementation			
Ref.	Contributory/Qualitative Factors to Potential Peat Failure	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating	Control Required	Control measures to be implemented during construction	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating
1	FOS = n/a (u), n/a (d)	1	3	3	Negligible	No	See Below	1	3	3	Negligible
2	Evidence of sub peat water flow	1	3	3	Negligible	No		1	3	3	Negligible
3	Evidence of surface water flow	1	3	3	Negligible	No		1	3	3	Negligible
4	Evidence of previous failures/slips	0	3	0	Not Applicable	No		0	3	0	Not Applicable
5	Type of vegetation	1	3	3	Negligible	No		1	3	3	Negligible
6	General slope characteristics upslope/downslope from infrastructure location	2	3	6	Low	No		2	3	6	Low
7	Evidence of very soft/soft clay at base of peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
8	Evidence of mechanically cut peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
9	Evidence of quaking or buoyant peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
10	Evidence of bog pools	0	3	0	Not Applicable	No		0	3	0	Not Applicable
11	Other	0	3	0	Not Applicable	No		0	3	0	Not Applicable

	Control Measures to be Implemented Prior to/and During Construction for **Turbine T3**
	Not applicable - No peat recorded at proposed infrastructure location

Note
(1) FOS abbreviations are: u: FOS for undrained analysis, d: FOS for drained analysis.
(2) Probability assessed as per Table A and B of Appendix E.
(3) Impact based on distance of infrastructure element to nearest watercourse.

Bracklyn Wind Farm - Peat Stability Risk Register (Rev 0)

Location:	**Turbine T4**

Grid Reference (Eastings, Northings):	**661188**	**757707**
Distance to Watercourse (m)	**> 150**	
Min & Max Measured Peat Depth (m):	**0.2 - 0.3**	
Control Required:	**No**	

		Pre-Control Measure Implementation						Post-Control Measure Implementation			
Ref.	Contributory/Qualitative Factors to Potential Peat Failure	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating	Control Required	Control measures to be implemented during construction	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating
1	FOS = 17.64 (u), 19.09 (d)	1	1	1	Negligible	No	See Below	1	1	1	Negligible
2	Evidence of sub peat water flow	1	1	1	Negligible	No		1	1	1	Negligible
3	Evidence of surface water flow	1	1	1	Negligible	No		1	1	1	Negligible
4	Evidence of previous failures/slips	0	1	0	Not Applicable	No		0	1	0	Not Applicable
5	Type of vegetation	1	1	1	Negligible	No		1	1	1	Negligible
6	General slope characteristics upslope/downslope from infrastructure location	2	1	2	Negligible	No		2	1	2	Negligible
7	Evidence of very soft/soft clay at base of peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
8	Evidence of mechanically cut peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
9	Evidence of quaking or buoyant peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
10	Evidence of bog pools	0	1	0	Not Applicable	No		0	1	0	Not Applicable
11	Other	0	1	0	Not Applicable	No		0	1	0	Not Applicable

	Control Measures to be Implemented Prior to/and During Construction for **Turbine T4**
i	Maintain hydrology of area as far as possible;
ii	Use of experienced geotechnical staff for site investigation;
iii	Use of experienced contractors and trained operators to carry out the work;
iv	Detailed ground investigation to determine peat, mineral soil and bedrock condition and properties.

Note
(1) FOS abbreviations are: u: FOS for undrained analysis, d: FOS for drained analysis.
(2) Probability assessed as per Table A and B of Appendix E.
(3) Impact based on distance of infrastructure element to nearest watercourse.

Bracklyn Wind Farm - Peat Stability Risk Register (Rev 0)

Location:	Turbine T5	
Grid Reference (Eastings, Northings):	660780	757320
Distance to Watercourse (m)	> 150	
Min & Max Measured Peat Depth (m):	0.5 - 1.0	
Control Required:	No	

		Pre-Control Measure Implementation						Post-Control Measure Implementation			
Ref.	Contributory/Qualitative Factors to Potential Peat Failure	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating	Control Required	Control measures to be implemented during construction	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating
1	FOS = 7.65 (u), 8.28 (d)	1	1	1	Negligible	No	See Below	1	1	1	Negligible
2	Evidence of sub peat water flow	1	1	1	Negligible	No		1	1	1	Negligible
3	Evidence of surface water flow	1	1	1	Negligible	No		2	1	2	Negligible
4	Evidence of previous failures/slips	0	1	0	Not Applicable	No		0	1	0	Not Applicable
5	Type of vegetation	2	1	2	Negligible	No		2	1	2	Negligible
6	General slope characteristics upslope/downslope from infrastructure location	2	1	2	Negligible	No		2	1	2	Negligible
7	Evidence of very soft/soft clay at base of peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
8	Evidence of mechanically cut peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
9	Evidence of quaking or buoyant peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
10	Evidence of bog pools	0	1	0	Not Applicable	No		0	1	0	Not Applicable
11	Other	0	1	0	Not Applicable	No		0	1	0	Not Applicable

	Control Measures to be Implemented Prior to/and During Construction for **Turbine T5**
i	Maintain hydrology of area as far as possible;
ii	Use of experienced geotechnical staff for site investigation;
iii	Use of experienced contractors and trained operators to carry out the work;
iv	Detailed ground investigation to determine peat, mineral soil and bedrock condition and properties.

Note
(1) FOS abbreviations are: u: FOS for undrained analysis, d: FOS for drained analysis.
(2) Probability assessed as per Table A and B of Appendix E.
(3) Impact based on distance of infrastructure element to nearest watercourse.

Bracklyn Wind Farm - Peat Stability Risk Register (Rev 0)

Location:	Turbine T6	
Grid Reference (Eastings, Northings):	661425	758848
Distance to Watercourse (m)	> 150	
Min & Max Measured Peat Depth (m):	0.5 - 1.0	
Control Required:	No	

		Pre-Control Measure Implementation						Post-Control Measure Implementation			
Ref.	Contributory/Qualitative Factors to Potential Peat Failure	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating	Control Required	Control measures to be implemented during construction	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating
1	FOS = 22.92 (u), 24.82 (d)	1	3	3	Negligible	No	See Below	1	3	3	Negligible
2	Evidence of sub peat water flow	1	3	3	Negligible	No		1	3	3	Negligible
3	Evidence of surface water flow	2	3	6	Low	No		2	3	6	Low
4	Evidence of previous failures/slips	0	3	0	Not Applicable	No		0	3	0	Not Applicable
5	Type of vegetation	2	3	6	Low	No		2	3	6	Low
6	General slope characteristics upslope/downslope from infrastructure location	2	3	6	Low	No		2	3	6	Low
7	Evidence of very soft/soft clay at base of peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
8	Evidence of mechanically cut peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
9	Evidence of quaking or buoyant peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
10	Evidence of bog pools	0	3	0	Not Applicable	No		0	3	0	Not Applicable
11	Other	0	3	0	Not Applicable	No		0	3	0	Not Applicable

	Control Measures to be Implemented Prior to/and During Construction for **Turbine T6**
i	Maintain hydrology of area as far as possible;
ii	Use of experienced geotechnical staff for site investigation;
iii	Use of experienced contractors and trained operators to carry out the work;
iv	Detailed ground investigation to determine peat, mineral soil and bedrock condition and properties.

Note
(1) FOS abbreviations are: u: FOS for undrained analysis, d: FOS for drained analysis.
(2) Probability assessed as per Table A and B of Appendix E.
(3) Impact based on distance of infrastructure element to nearest watercourse.

Bracklyn Wind Farm - Peat Stability Risk Register (Rev 0)

Location:	Turbine T7	
Grid Reference (Eastings, Northings):	661617	758418
Distance to Watercourse (m)	> 150	
Min & Max Measured Peat Depth (m):	0.3 - 1.0	
Control Required:	No	

		Pre-Control Measure Implementation						Post-Control Measure Implementation			
Ref.	Contributory/Qualitative Factors to Potential Peat Failure	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating	Control Required	Control measures to be implemented during construction	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating
1	FOS = 22.92 (u), 24.82 (d)	1	3	3	Negligible	No	See Below	1	3	3	Negligible
2	Evidence of sub peat water flow	1	3	3	Negligible	No		1	3	3	Negligible
3	Evidence of surface water flow	2	3	6	Low	No		2	3	6	Low
4	Evidence of previous failures/slips	0	3	0	Not Applicable	No		0	3	0	Not Applicable
5	Type of vegetation	2	3	6	Low	No		2	3	6	Low
6	General slope characteristics upslope/downslope from infrastructure location	2	3	6	Low	No		2	3	6	Low
7	Evidence of very soft/soft clay at base of peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
8	Evidence of mechanically cut peat	2	3	6	Low	No		2	3	6	Low
9	Evidence of quaking or buoyant peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
10	Evidence of bog pools	0	3	0	Not Applicable	No		0	3	0	Not Applicable
11	Other	0	3	0	Not Applicable	No		0	3	0	Not Applicable

	Control Measures to be Implemented Prior to/and During Construction for **Turbine T7**
i	Maintain hydrology of area as far as possible;
ii	Use of experienced geotechnical staff for site investigation;
iii	Use of experienced contractors and trained operators to carry out the work;
iv	Detailed ground investigation to determine peat, mineral soil and bedrock condition and properties.

Note
(1) FOS abbreviations are: u: FOS for undrained analysis, d: FOS for drained analysis.
(2) Probability assessed as per Table A and B of Appendix E.
(3) Impact based on distance of infrastructure element to nearest watercourse.

Bracklyn Wind Farm - Peat Stability Risk Register (Rev 0)

Location:	**Turbine T10**

Grid Reference (Eastings, Northings):	**662348**	**758513**
Distance to Watercourse (m)	**50 - 100**	
Min & Max Measured Peat Depth (m):	**1.6 - 2.5**	
Control Required:	**No**	

		Pre-Control Measure Implementation						Post-Control Measure Implementation			
Ref.	Contributory/Qualitative Factors to Potential Peat Failure	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating	Control Required	Control measures to be implemented during construction	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating
1	FOS = 13.1 (u), 14.18 (d)	1	3	3	Negligible	No	See Below	1	3	3	Negligible
2	Evidence of sub peat water flow	1	3	3	Negligible	No		1	3	3	Negligible
3	Evidence of surface water flow	1	3	3	Negligible	No		1	3	3	Negligible
4	Evidence of previous failures/slips	0	3	0	Not Applicable	No		0	3	0	Not Applicable
5	Type of vegetation	3	3	9	Low	No		1	3	3	Negligible
6	General slope characteristics upslope/downslope from infrastructure location	1	3	3	Negligible	No		1	3	3	Negligible
7	Evidence of very soft/soft clay at base of peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
8	Evidence of mechanically cut peat	1	3	3	Negligible	No		1	3	3	Negligible
9	Evidence of quaking or buoyant peat	0	3	0	Not Applicable	No		0	3	0	Not Applicable
10	Evidence of bog pools	0	3	0	Not Applicable	No		0	3	0	Not Applicable
11	Other	0	3	0	Not Applicable	No		0	3	0	Not Applicable

	Control Measures to be Implemented Prior to/and During Construction for **Turbine T10**
i	Maintain hydrology of area as far as possible;
ii	Use of experienced geotechnical staff for site investigation;
iii	Use of experienced contractors and trained operators to carry out the work;
iv	Detailed ground investigation to determine peat, mineral soil and bedrock condition and properties.

Note
(1) FOS abbreviations are: u: FOS for undrained analysis, d: FOS for drained analysis.
(2) Probability assessed as per Table A and B of Appendix E.
(3) Impact based on distance of infrastructure element to nearest watercourse.

Bracklyn Wind Farm - Peat Stability Risk Register (Rev 0)

Location:	Turbine T11	
Grid Reference (Eastings, Northings):	662152	758072
Distance to Watercourse (m)	> 150	
Min & Max Measured Peat Depth (m):	0.0	
Control Required:	No	

		Pre-Control Measure Implementation						Post-Control Measure Implementation			
Ref.	Contributory/Qualitative Factors to Potential Peat Failure	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating	Control Required	Control measures to be implemented during construction	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating
1	FOS = n/a (u), n/a (d)	1	1	1	Negligible	No	See Below	1	1	1	Negligible
2	Evidence of sub peat water flow	1	1	1	Negligible	No		1	1	1	Negligible
3	Evidence of surface water flow	1	1	1	Negligible	No		1	1	1	Negligible
4	Evidence of previous failures/slips	0	1	0	Not Applicable	No		0	1	0	Not Applicable
5	Type of vegetation	2	1	2	Negligible	No		2	1	2	Negligible
6	General slope characteristics upslope/downslope from infrastructure location	1	1	1	Negligible	No		1	1	1	Negligible
7	Evidence of very soft/soft clay at base of peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
8	Evidence of mechanically cut peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
9	Evidence of quaking or buoyant peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
10	Evidence of bog pools	0	1	0	Not Applicable	No		0	1	0	Not Applicable
11	Other	0	1	0	Not Applicable	No		0	1	0	Not Applicable

	Control Measures to be Implemented Prior to/and During Construction for **Turbine T11**
	Not applicable - No peat recorded at proposed infrastructure location

Note
(1) FOS abbreviations are: u: FOS for undrained analysis, d: FOS for drained analysis.
(2) Probability assessed as per Table A and B of Appendix E.
(3) Impact based on distance of infrastructure element to nearest watercourse.

Bracklyn Wind Farm - Peat Stability Risk Register (Rev 0)

Location:	Substation	
Grid Reference (Eastings, Northings):	661172	758511
Distance to Watercourse (m)	> 150	
Min & Max Measured Peat Depth (m):	1.00	
Control Required:	No	

		Pre-Control Measure Implementation						Post-Control Measure Implementation			
Ref.	Contributory/Qualitative Factors to Potential Peat Failure	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating	Control Required	Control measures to be implemented during construction	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating
1	FOS = 11.11.47 47 (u), (d)	1	1	1	Negligible	No	See Below	1	1	1	Negligible
2	Evidence of sub peat water flow	1	1	1	Negligible	No		1	1	1	Negligible
3	Evidence of surface water flow	1	1	1	Negligible	No		1	1	1	Negligible
4	Evidence of previous failures/slips	0	1	0	Not Applicable	No		0	1	0	Not Applicable
5	Type of vegetation	2	1	2	Negligible	No		2	1	2	Negligible
6	General slope characteristics upslope/downslope from infrastructure location	1	1	1	Negligible	No		1	1	1	Negligible
7	Evidence of very soft/soft clay at base of peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
8	Evidence of mechanically cut peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
9	Evidence of quaking or buoyant peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
10	Evidence of bog pools	0	1	0	Not Applicable	No		0	1	0	Not Applicable
11	Other	0	1	0	Not Applicable	No		0	1	0	Not Applicable

	Control Measures to be Implemented Prior to/and During Construction for **Substation**
i	Maintain hydrology of area as far as possible;
ii	Use of experienced geotechnical staff for site investigation;
iii	Use of experienced contractors and trained operators to carry out the work;
iv	Detailed ground investigation to determine peat, mineral soil and bedrock condition and properties.

Note
(1) FOS abbreviations are: u: FOS for undrained analysis, d: FOS for drained analysis.
(2) Probability assessed as per Table A and B of Appendix D.
(3) Impact based on distance of infrastructure element to nearest watercourse.

Bracklyn Wind Farm - Peat Stability Risk Register (Rev 0)

Location:	**Met Mast**	
Grid Reference (Eastings, Northings):	**660639**	**757853**
Distance to Watercourse (m)	**> 150**	
Min & Max Measured Peat Depth (m):	**0.0**	
Control Required:	**No**	

		Pre-Control Measure Implementation						Post-Control Measure Implementation			
Ref.	Contributory/Qualitative Factors to Potential Peat Failure	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating	Control Required	Control measures to be implemented during construction	Prob (Note 2)	Impact (Note 3)	Risk	Risk Rating
1	FOS = n/a (u), n/a (d)	1	1	1	Negligible	No	See Below	1	1	1	Negligible
2	Evidence of sub peat water flow	1	1	1	Negligible	No		1	1	1	Negligible
3	Evidence of surface water flow	1	1	1	Negligible	No		1	1	1	Negligible
4	Evidence of previous failures/slips	0	1	0	Not Applicable	No		0	1	0	Not Applicable
5	Type of vegetation	2	1	2	Negligible	No		2	1	2	Negligible
6	General slope characteristics upslope/downslope from infrastructure location	1	1	1	Negligible	No		1	1	1	Negligible
7	Evidence of very soft/soft clay at base of peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
8	Evidence of mechanically cut peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
9	Evidence of quaking or buoyant peat	0	1	0	Not Applicable	No		0	1	0	Not Applicable
10	Evidence of bog pools	0	1	0	Not Applicable	No		0	1	0	Not Applicable
11	Other	0	1	0	Not Applicable	No		0	1	0	Not Applicable

	Control Measures to be Implemented Prior to/and During Construction for **Met Mast**
	Not applicable - No peat recorded at proposed infrastructure location

Note
(1) FOS abbreviations are: u: FOS for undrained analysis, d: FOS for drained analysis.
(2) Probability assessed as per Table A and B of Appendix D.
(3) Impact based on distance of infrastructure element to nearest watercourse.

FEHILY TIMONEY
30 YEARS

CONSULTANTS IN ENGINEERING,
ENVIRONMENTAL SCIENCE & PLANNING

APPENDIX B

Calculated FOS for Peat Slopes on Site

Calculated FoS of Natural Peat Slopes for Brackyn Wind Farm - Undrained Analysis

Turbine No./Waypoint	Easting	Northing	Slope	Undrained shear strength	Bulk unit weight of Peat	Peat Depth	Surcharge Equivalent Placed Fill Depth (m)	Factor of Safety for Load Condition	
			β (deg)	c_u (kPa)	γ (kN/m^3)	(m)	Condition (2)	Condition (1)	Condition (2)
T1	660970	759136		No peat encountered					
T2	660780	758679		No peat encountered					
T3	660893	758066		No peat encountered					
T4	661188	757707	2	8	10	0.3	1.3	**76.46**	**17.64**
T5	660780	757320	3	8	10	1.0	2.0	**15.31**	**7.65**
T6	661425	758848	1	8	10	1.0	2.0	**45.85**	**22.92**
T7	661617	758418	1	8	10	1.0	2.0	**45.85**	**22.92**
T10	662348	758513	1	8	10	2.5	3.5	**18.34**	**13.10**
T11	662152	758072	1	No peat encountered					
WP001	661923	758489	3	8	10	0.1	1.1	**306.14**	**14.58**
WP002	661973	758495	3	8	10	0.1	1.1	**306.14**	**14.58**
WP003	662021	758509	3	8	10	0.2	1.2	**102.05**	**13.31**
WP004	662068	758524	3	8	10	0.20	1.2	**76.53**	**12.76**
WP005	662118	758531	3	8	10	0.1	1.1	**153.07**	**13.92**
WP006	662168	758533	3	8	10	0.2	1.2	**76.53**	**12.76**
WP009	662318	758532	3	8	10	0.05	1.1	**306.14**	**14.58**
WP010	662367	758527	3	8	10	0.05	1.1	**306.14**	**14.58**
WP011	662272	758559	3	8	10	0.6	1.6	**25.51**	**9.57**
1	661923	758489	3	8	10	0.05	1.1	**306.14**	**14.58**
2	661973	758495	1	8	10	0.1	1.1	**458.46**	**41.68**
4	662068	758524	1	8	10	0.6	1.6	**76.41**	**28.65**
6	662168	758533	1	8	10	0.85	1.9	**53.94**	**24.78**
8	662268	758536	1	8	10	1.6	2.6	**28.65**	**17.63**
13	661369	758622	1	8	10	0.2	1.2	**229.23**	**38.20**
14	661372	758698	1	8	10	0.1	1.1	**458.46**	**41.68**
17	661985	758368	1	8	10	0.2	1.2	**229.23**	**38.20**
18	662073	758246	1	8	10	0.1	1.1	**458.46**	**41.68**
Substation	661172	758511	2	8	10	1	2.0	**22.94**	**11.47**
Met mast	660639	757853	1	No peat encountered					
							Minimum =	**15.31**	**7.65**
							Maximum =	**458.46**	**41.68**
							Average =	**174.25**	**20.98**

Notes:

(1) Assuming a bulk unit weight for peat of 10kN/m^3
(2) Assuming a surcharge equivalent to fill depth of 1m of peat i.e. 10kPa.
(3) Slope inclination (β) based on site readings and site contour plans.
(4) A lower bound undrained shear strength, cu for the peat of 8kPa was selected for the assessment. It should be noted that a cu of 8kPa for the peat is considered a conservative value for the analysis and is not representative of all peat present across the site. In reality the peat has a significantly higher undrained strength.
(5) Peat depths based on probes carried out by FT.
(6) For load conditions see report text.

Calculated FoS of Natural Peat Slopes for Bracklyn Wind Farm - Drained Analysis

Turbine No./Waypoint	Slope	Design c'	Bulk unit weight of Peat	Unit weight of Water	Depth of In situ Peat	Friction Angle	Surcharge Equivalent Placed Fill	Equivalent Total Depth of Peat (m)	Factor of Safety for Load Condition	
	α (deg)	c' (kPa)	γ (kN/m^3)	γ_w (kN/m^3)	(m)	ø' (deg)	Condition (2)	Condition (2)	Condition (1)	Condition (2)
									100% Water	100% Water
T1		4	10.0	10.0	No peat encountered					
T2		4	10.0	10.0	No peat encountered					
T3		4	10.0	10.0	No peat encountered					
T4	2	4	10.0	10.0	0.3	25	1.0	1.3	**38.23**	**19.09**
T5	3	4	10.0	10.0	1.0	25	1.0	2.0	**7.65**	**8.28**
T6	1	4	10.0	10.0	1.0	25	1.0	2.0	**22.92**	**24.82**
T7	1	4	10.0	10.0	1.0	25	1.0	2.0	**22.92**	**24.82**
T10	1	4	10.0	10.0	2.5	25	1.0	3.5	**9.17**	**14.18**
T11	1	4	10.0	10.0	No peat encountered					
WP001	3	4	10.0	10.0	0.1	25	1.0	1.1	**153.07**	**15.76**
WP002	3	4	10.0	10.0	0.1	25	1.0	1.1	**153.07**	**15.76**
WP003	3	4	10.0	10.0	0.2	25	1.0	1.2	**51.02**	**14.39**
WP004	3	4	10.0	10.0	0.20	25	1.0	1.2	**38.27**	**13.79**
WP005	3	4	10.0	10.0	0.1	25	1.0	1.1	**76.53**	**15.05**
WP006	3	4	10.0	10.0	0.2	25	1.0	1.2	**38.27**	**13.79**
WP009	3	4	10.0	10.0	0.05	25	1.0	1.1	**153.07**	**15.76**
WP010	3	4	10.0	10.0	0.05	25	1.0	1.1	**153.07**	**15.76**
WP011	3	4	10.0	10.0	0.6	25	1.0	1.6	**12.76**	**10.34**
1	3	4	10.0	10.0	0.05	25	1.0	1.1	**153.07**	**15.76**
2	1	4	10.0	10.0	0.1	25	1.0	1.1	**229.23**	**45.13**
4	1	4	10.0	10.0	0.6	25	1.0	1.6	**38.20**	**31.02**
6	1	4	10.0	10.0	0.85	25	1.0	1.9	**26.97**	**26.83**
8	1	4	10.0	10.0	1.6	25	1.0	2.6	**14.33**	**19.09**
13	1	4	10.0	10.0	0.2	25	1.0	1.2	**114.61**	**41.36**
14	1	4	10.0	10.0	0.1	25	1.0	1.1	**229.23**	**45.13**
17	1	4	10.0	10.0	0.2	25	1.0	1.2	**114.61**	**41.36**
18	1	4	10.0	10.0	0.1	25	1.0	1.1	**229.23**	**45.13**
Substation	2	4	10.0	10.0	1	25	1.0	2.0	**11.47**	**12.41**
Met mast	1	4	10.0	10.0	No peat encountered					

	Condition (1)	Condition (2)
Minimum =	**7.65**	**8.28**
Maximum =	**229.23**	**45.13**
Average =	**87.12**	**22.70**

Notes:

(1) Assuming a bulk unit weight of peat of 10 (kN/m^3)
(2) Assuming a surcharge equivalent to fill depth of 1.0m.
(3) Slope inclination (β) based on site readings and contour survey plans of site.
(4) FoS is based on slope inclination and shear test results obtained from published data.
(5) Peat depths based on probes carried out by FT.
(6) For load conditions see Report text.
(7) Minimum acceptable factor of safety required of 1.3 for first-time failures based on BS: 6031:1981 Code of practice for Earthworks.

CONSULTANTS IN ENGINEERING,
ENVIRONMENTAL SCIENCE & PLANNING

APPENDIX C

Methodology for Peat Stability Risk Assessment

Methodology for Peat Stability Risk Assessment

A peat stability risk assessment was carried out for each of the main infrastructure elements at the proposed wind farm development. This approach takes into account guidelines for geotechnical/peat stability risk assessments as given in PLHRAG (2017) and MacCulloch (2005). The degree of risk is determined as a Risk Rating (R), which is the product of probability (P) and impact (I). How these factors are determined and applied in the analysis is described below.

The main approaches for assessing peat stability include the following:

(a) Geomorphological

(b) Qualitative (judgement)

(c) Index/Probabilistic (probability)

(d) Deterministic (factor of safety)

Approaches (a) to (c) listed above would be considered subjective and do not provide a definitive indication of stability; in addition, a high level of judgement/experience is required which makes it difficult to relate the findings to real conditions. FT apply a more objective approach, the deterministic approach. As part of FT's deterministic approach, a qualitative risk assessment is also carried out taking into account qualitative factors, which cannot necessarily be quantified.

Probability

The likelihood of a peat failure occurring was assessed based on the results of both the quantitative results of stability calculations (deterministic approach using factors of safety) and the assessment of the severity of several qualitative factors which cannot be reasonably included in a stability calculation but nevertheless may affect the occurrence of peat instability.

The qualitative factors used in the risk assessment are outlined in Table A and have been compiled based on FT's experience of assessments and construction in peat land sites and peat failures throughout Ireland and the UK.

Table A: Qualitative Factors used to Assess Potential for Peat Failure

Qualitative Factor	Type of Feature/Indicator for each Qualitative Factor [1]	Explanation/Description of Qualitative Factor
Evidence of sub peat water flow	No	Based on site walkover observations. Sub peat water flow generally occurs in the form of natural piping at the base of peat. Where there is a constriction or blockage in natural pipes a build-up of water can occur at the base of the peat causing a reduction in effective stress at the base of the peat resulting in failure; this is particularly critical during periods of intense rainfall.
	Possibly	
	Probably	
	Yes	

Qualitative Factor	Type of Feature/Indicator for each Qualitative Factor [1]	Explanation/Description of Qualitative Factor
Evidence of surface water flow	Dry	Based on site walkover observations. The presence of surface water flow indicates if peat in an area is well drained or saturated and if any additional loading from the ponding of surface water onto the peat is likely.
	Localised/Flowing in drains	
	Ponded in drains	
	Springs/surface water	
Evidence of previous failures/slips	No	Based on site walkover observations. The presence of clustering of relict failures may indicate that particular pre-existing site conditions predispose a site to failure.
	In general area	
	On site	
	Within 500m of location	
Type of vegetation	Grass/Crops	Based on site walkover observations. The type of vegetation present indicates if peat in an area is well drained, saturated, etc. Vegetation that indicates wetter ground may also indicate softer underlying peat deposits.
	Improved Grass/Dry Heather	
	Wet Grassland/Juncus (Rushes)	
	Wetlands Sphagnum (Peat moss)	
General slope characteristics upslope/downslope from infrastructure location	Concave	Based on site walkover observations. Slope morphology in the area of the infrastructure location is an important factor. A number of recorded peat failures have occurred in close proximity to a convex break in slope.
	Planar to concave	
	Planar to convex	
	Convex	
Evidence of very soft/soft clay at base of peat	No	Based on inspection of exposures in general area from site walkover. Several reported peat failures identify the presence of a weak layer at the base of the peat along which shear failure has occurred.
	Yes	
Evidence of mechanically cut peat	No	Based on site walkover observations. Mechanically cut peat typically cut using a ‘sausage’ machine to extract

Qualitative Factor	Type of Feature/Indicator for each Qualitative Factor [1]	Explanation/Description of Qualitative Factor
	Yes	peat for harvesting. Areas which have been cut in this manner have been linked to peat instability. The mechanical cuts can notably reduce the intrinsic strength of the peat and also allow ingress of rainfall/surface water.
Evidence of quaking or buoyant peat	No	Based on site walkover observations. Quaking/buoyant peat is indicative of highly saturated peat, which would generally be considered to have a low strength. Quaking peat is a feature on sites that have been previously linked with peat instability.
	Yes	
Evidence of bog pools	No	Based on site walkover observations. Bog pools are generally an indicator of areas of weak, saturated peat. Commonly where there are open areas of water within peat these can be interconnected, with the result that there may be sub-surface bodies of water. The presence of bog pools have been previously linked with peat instability.
	Yes	
Other	Varies	In addition to the above features/ indicators and based on site recordings the following are some of the features which may be identified: Excessively deep peat, weak peat, overly steep slope angles, etc.

Note (1) The list of features/indicators for each qualitative factor are given in increasing order of probability of leading to peat instability/failure.

It should be noted that the presence of one of the qualitative factors alone from Table A is unlikely to lead to peat instability/failure. Peat instability/failure at a site is generally the combination of a number of these factors occurring at the same time at a particular location. The probability rating assigned to the quantitative and qualitative factors is judged on a 5-point scale from 1 (indicating negligible or no probability of failure) to 5 (indicating a very likely failure), as outlined in Table B.

Table B: Probability Scale

Scale	Factor of Safety	Probability
1	1.30 or greater	Negligible/None
2	1.29 to 1.20	Unlikely
3	1.19 to 1.11	Likely
4	1.01 to 1.10	Probable
5	≤1.0	Very Likely

Scale	Likelihood of Qualitative Factor leading to Peat Failure	Probability of Failure
1	Negligible/None	Least
2	Unlikely	
3	Probable	
4	Likely	
5	Very Likely	Greatest

Impact

The severity of the risk is also assessed qualitatively in terms of impact. The impact of a peat failure on the environment within and beyond the immediate wind farm site is assessed based on the potential travel distance of a peat failure. Where a peat failure enters a watercourse, it can travel a considerable distance downstream. Therefore, the proximity of a potential peat failure to a drainage course is a significant indicator of the likely potential impact.

The risk is determined based on the combination of hazard and impact. A qualitative scale has been derived for the impact of the hazard based on distance of infrastructure element to a watercourse (Table C).

The location of watercourses is based on topographic maps and supplemented by site observations from walkover survey. Note that not all watercourses are shown on maps.

Table C: Impact Scale

Scale	Criteria	Impact
1	Proposed infrastructure element greater than 150m of watercourse	Negligible/None
2	Proposed infrastructure element within 150 to 101m of watercourse	Low
3	Proposed infrastructure element within 100 to 51m of watercourse	Medium

4	Proposed infrastructure element within 50 m of watercourse	High
5	Proposed infrastructure element within 50 m of watercourse, in an environmentally sensitive area	Extremely High

Risk Rating

The degree of risk is determined as the product of probability (P) and impact (I), which gives the Risk Rating (R) as follows:

The Risk Rating is calculated from: R = P x I

Due to the 5-point scales used to assess Probability and Impact, the Risk Rating can range from 1 to 25 as shown in Table D.

Table D: Qualitative Risk Rating

		Probability				
		1	**2**	**3**	**4**	**5**
Impact	**5**	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5

Risk Rating & Control Measures	
17 to 25	High: avoid working in area or significant control measures required
11 to 16	Medium: notable control measures required
5 to 10	Low: only routine control measures required
1 to 4	Negligible: none or only routine control measures required

The risk rating is calculated individually for each contributory factor. Control measures are required to reduce the risk to at least a ‘Low’ risk rating. The control measures in response to the qualitative risk ratings are included in the peat stability risk registers for each main infrastructure element in Appendix A.

The risk rating is calculated individually for each contributory factor. Control measures are required to reduce the risk to at least a ‘Tolerable’ risk rating

FEHILY TIMONEY

30 YEARS

CONSULTANTS IN ENGINEERING, ENVIRONMENTAL SCIENCE & PLANNING

www.fehilytimoney.ie

CORK OFFICE
Core House
Pouladuff Road,
Cork, T12 D773,
Ireland
+353 21 496 4133

Dublin Office
J5 Plaza,
North Park Business Park,
North Road, Dublin 11, D11 PXT0,
Ireland
+353 1 658 3500

Carlow Office
Unit 6
Bagenalstown Industrial Park,
Bagenalstown, Co. Carlow,
R21 XA81, Ireland
+353 59 972 3800