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Investigation into the likely cause of peat failure at Ballincollig Hill Wind Farm, Ireland

Enquête sur la cause probable de l'échec de la tourbe au parc éolien de Ballincollig Hill, en Irlande

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ABSTRACT: Ground conditions at the Ballincollig Hill wind farm site consist of soft to very soft, fibrous to amorphous peat located on gently sloping terrain. The blanket peat at the site had a history of mechanical peat cutting, which resulted in the dissection of the strongest peat, the upper acrotelm layer, for the formation of multiple cuts and drains. These cuts exposed the lower weaker peat to significant rainfall in the summer months prior to the peat failure. In late August 2008, construction of a floating access track resulted in additional loading of the peat and is considered directly related to the peat failure. Observations from site inspections found that the ability of surface water to drain from the peat was affected by the orientation and number of drains/cuts. The impact of floating track construction led to initially localised failure and rapidly to progressive large-scale peat failure. The paper presents lessons learnt and consideration of risks to floating track construction in similar terrain.

RÉSUMÉ: Les conditions de sol sur le site du parc éolien de Ballincollig Hill consister en une tourbe molle à très douce, fibreuse à amorphe située sur un terrain en pente douce. La tourbe de couverture sur le site avait des antécédents de coupe mécanique de la tourbe, ce qui a entraîné la dissection de la tourbe la plus forte, la couche d'acrotelme supérieure, pour la formation de multiples coupes et drains. Ces coupes ont exposé la tourbe la plus faible et la plus faible à des précipitations importantes pendant les mois d'été précédant la rupture de la tourbe. À la fin d'août 2008, la construction d'une voie d'accès flottante a entraîné une charge supplémentaire de la tourbe et est considérée comme directement liée à la défaillance de la tourbe. Les observations faites lors des inspections sur les lieux ont révélé que l'orientation et le nombre de drains / de coupes influaient sur la capacité de l'eau de surface à s'écouler de la tourbe. L'impact de la construction d'une voie flottante a conduit à une défaillance initialement localisée et à une dégradation rapide et progressive de la tourbe. Le document présente les enseignements tirés et prend en compte les risques pour la construction de voies flottantes sur un terrain similaire.

Keywords: Blanket peat; peat failure; access track construction.

1 INTRODUCTION

Ballincollig Hill wind farm located approximately 7km north east of Tralee, south west Ireland, was constructed in a mountainous area overlain with blanket peat. A peat failure occurred at the wind farm site on the 22nd August 2008 which coincided with the construction of a floated access track. A floated access track is constructed directly on the surface of the in-situ peat and relies on the strength of the underlying peat for support.

At the location of the failure the topography generally comprised a uniform peat slope, typically 3 degrees, falling towards the Glashoreag River. The failure occurred within an area of intact, mechanically cut and locally cut-over blanket peat.

Intact blanket peat refers to an undisturbed peatland area. Mechanically cut peat refers to an area which has been cut using chainsaw/sausage machines for the purpose of peat harvesting/turf production. Cut-over peat refers to an area where peat has been extracted in the past.

As a result of the failure a considerable volume of peat was displaced downslope (Figure 1) and entered the Glashoreag River.

Figure 1. Movement of peat towards the Glashoreag River

The aim of this study is to show that the peat failure was caused by a combination of factors including the construction of a floating access track. This study also presents the findings and lessons learned from the failure at Ballincollig Hill.

2 DESCRIPTION OF PEAT FAILURE

The peat failure occurred 100 to 200m south of a small tributary of the Glashoreag River and downslope of a floated access track that was under construction.

2.1 Failure scar

The failure scar was essentially rectangular in plan, measuring about 520m in length and varying between 50 to 100m in width. The shape of the failure scar was controlled to a large extent by the mechanical cuts which were formed during previous operations for turf production. Blanket peat in the north of the failure scar detached along the lines from mechanical cuts and moved as strips or rafts of peat (Figure 1 and 2). There were several locations along the failure scar where the peat debris accumulated on the intact peat.

Figure 2. Detachment of peat into strips along mechanical cuts

2.2 Failure type

Initially the peat movement occurred by translational sliding followed by peat flow as the mass moved downslope resulting in a loss of undrained shear strength and structure of the peat. Failure also occurred along the northern edge of the scar by sliding/flow as peat separated along machine cuts, which resulted in an enlargement of the scar. Localised failure and enlargement of the scar also occurred due to slumping/toppling of the peat along the boundary of the scar.

There were several locations where peat debris from the failure and was deposited onto intact peat along the perimeter of the failure, including where the scar meets the Glashoreag River. On the southern side of the failure, upslope from an elongated debris deposit, there was a crumpled zone extending approximately 30m into the intact peat (Figure 3).

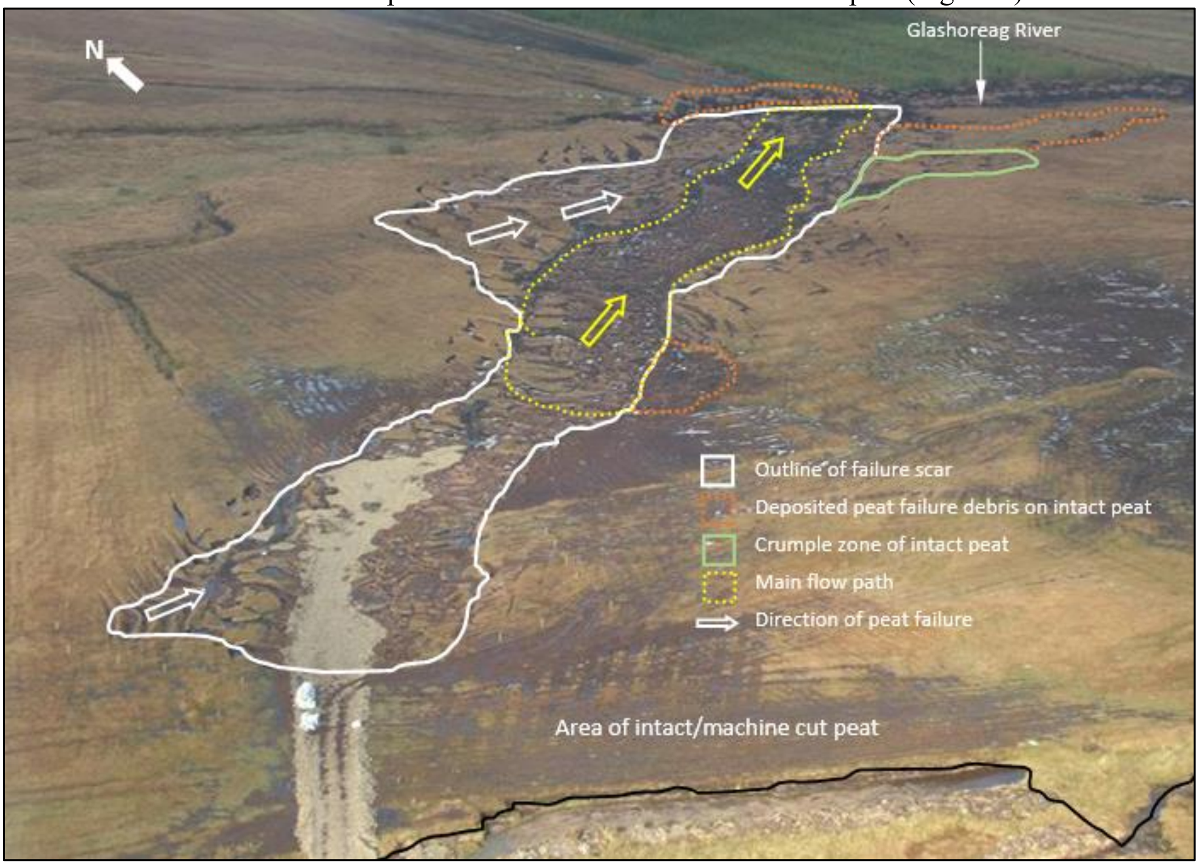

Figure 3. Morphological elements of the Ballincollig Hill failure

The crumpled zone represents the pressure or impact of the peat debris during the failure event.

Machine cuts were recorded in the peat surrounding the failure scar, and at the failure head there were multiple cuts on the southern side indicating multiple phases of cutting. Survey information of the failure scar showed that the approximate volume of peat displaced was 120,000m^3 with an estimated 63,000m^3 entering the Glashoreag River.

2.3 Ground conditions at the scar

From examination of exposures, the failure appeared to have occurred about 100 to 200mm above the base of the peat and not at the peat/mineral soil interface or within the mineral soil. Following inspection of the site around the failure scar the thickness of peat varied from about 2.5 to 3m, the upper 1 to 1.5m consisted of fibrous peat (acrotelm) overlying humified peat (catotelm) (Figure 4). Typically, the in-situ undrained shear strength of the acrotelm varied between 5 to 40kPa, while the catotelm undrained shear strength varied between 2.5 and 6kPa. It should be noted that in-situ field vane testing of peat, particularly within fibrous peat, can give an overestimated strength (Dykes and Jennings, 2008).

Figure 4. Typical composition of peat viewed from detached peat strips

3 ENGINEERING GEOLOGY

Following the peat failure at Ballincollig Hill, site inspections and intrusive ground investigation followed by laboratory testing of recovered samples were carried out. The site typically comprised the following soil and rock types:

3.1 Peat

The blanket peat was described as very soft to soft fibrous in the upper 1.5m grading to amorphous peat with an increase in depth (Figure 4). At the location of the failure the thickness of peat varied from about 2.5 to 3m. To the south of the failure scar the peat deposits were between 1 and 4.5m thick. The Von Post humification grading for the upper 1.5m of peat was relatively fibrous (humification of H3 to H5) with decreasing fibre content with depth (humification up to H8).

Direct simple shear testing of peat samples was carried out at University College Dublin and at the Norwegian Geotechnical Institute. The results showed that with low consolidation stresses, the shear strength was as low as 2kPa (Long et al, 2011).

Tensile strength testing of undisturbed samples of peat was also carried out by Kingston University. The apparatus used, and the procedure followed, are as detailed by Dykes (2008). The pattern of tensile strength results obtained from these tests suggests that the overall strength of the peat below the depth of the mechanically cut peat is likely to be less than 3 to 4kPa, possibly less than 2kPa, and that the high strengths recorded in samples closer to the surface can be attributed to the high density of fibres.

3.2 Glacial till & bedrock

Beneath the peat, glacial till can be found which in localised places grades into weathered rock. The glacial till was generally described as locally soft, firm to stiff sandy gravelly silt/clay with gravel and cobbles. The depth of the glacial till is not known; however it is likely to vary with thin deposits on the upper slope of Ballincollig Hill and deeper deposits in low lying areas.

The bedrock in the area comprises Feale Sandstone and the Glenoween Shale formations. The sandstone consists of brown to green sandstones and shale with occasional thin coal seams. The shale comprises dark grey silty mudstone (GSI, 1997).

4 FACTORS CONTRIBUTING TO FAILURE

4.1 Floating access track construction

The loading from the construction of the access track would have increased the applied stress through the full depth of the peat over the full width of the track. The additional loading applied onto areas where weak peat was present contributed towards the undrained shear failure of the peat.

The sudden impact loading of the peat surface, from end tipping granular fill to be used as a construction material, likely resulted in a bearing failure within the peat. The failure, initially localised beneath the loaded area, resulted in the development of shear planes and hence a loss of strength (Boylan et al, 2008). This localised area of peat with low undrained shear strength effectively failed. The failed area led to an increase in applied pressure to the peat downslope of the access track. This ultimately caused a progressive failure of the peat downslope and resulted in the peat failing initially by translational sliding, before progressing to peat flow.

Similarly sudden impact loading of the peat surface, from the end tipping of granular fill, could directly load water confined within the mechanical cuts. This would cause transmission of the impact load through the water into the peat at depth.

4.2 Peat harvesting

There was evidence of multiple phases of mechanical cuts in part of the bog surrounding the failure scar (Figure 5).

The mechanical cuts were about 1 to 1.5m deep and severed the acrotelm layer (upper fibrous layer) of the peat where most of the intrinsic (tensile) strength of the peat lies.

Due to the multitude of mechanical cuts it is likely that rainfall accumulated in the cuts and was prevented from draining away effectively which resulted in softening of the peat and a reduction in the undrained shear strength. Water retention within the cuts would have led to a lateral force being exerted onto adjacent peat and a resulting lateral displacement of the peat.

Where a bog is mechanically cut perpendicular to the contours then this can facilitate drainage of the bog. Where a bog is cut in various orientations then this can cause water to be retained in the cuts and additional lateral loads being introduced into the bog. Water retention within the mechanical cuts would have occurred particularly where the orientation of the cuts were parallel to the slope contours (i.e. cuts were across the slope).

Figure 5. Multiple machine cuts in intact surface of peat

4.3 Rainfall

The nearest weather stations to the site are located at Shannon Airport and Valentia Observatory, both of which are about 70km from site. Rainfall in the 7-day period prior to the failure was classed as low or close to average for August, ranging between 0 to 20mm with an average of 6.3mm daily rainfall. On the day of the failure there was no recorded rainfall however the monthly average up to that point was exceeded by between 160 and 230%. The Met Éireann weather report for August stated that “August was a month of exceptionally heavy rain over most of the country” (Met Éireann, 2018).

The antecedent rainfall during the first 21 days of August corresponded to about 90% of the total rainfall for the month and significantly occurred prior to the peat failure. This is highlighted in Figure 6 which shows the cumulative rainfall from both weather stations for the month of August in 2008. The significant rainfall before the peat failure would have resulted in a significant amount of water being retained within the mechanical cuts made during the peat harvesting operations.

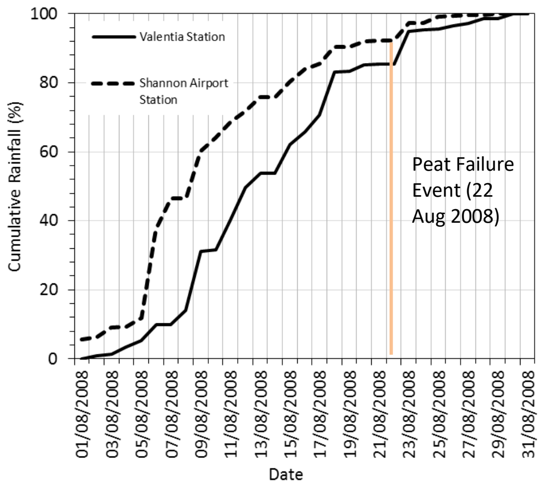

Figure 6. Rainfall records for the month of August 2008 (Met Éireann, 2018)

4.4 Weak peat

Peat characteristics can be spatially variable which can result in localised changes in strength. Weak peat in the failure area, where undrained shear strengths of 2.5 to 6kPa at depths greater than 1.5m were recorded, contributed to the peat failure.

4.5 Other factors

Whilst there may be other factors that have contributed to the failure, such as the natural ingress of water into the peat, lack of surface vegetation, it is considered that a critical combination of the above factors would be sufficient to explain the peat failure.

5 FINDINGS & LESSONS LEARNED

The following findings and lessons learned are given to reduce the potential of peat failure during construction of floated access tracks or similar works.

A comprehensive site reconnaissance to inspect the proposed footprint of access tracks should be carried out. Peat characteristics can be spatially variable which can result in localised changes in strength which can influence the stability of floating access tracks.

In addition to a number of other salient features, some visual indicators of change in peat strength that should be recorded during a site reconnaissance are summarised in Table 1.

Table 1. Summary of visual indicators

Visual Indicator	**Description**
Peat harvesting/ mechanically cut peat	Mechanical cuts sever the acrotelm layer (upper fibrous layer) of the peat where most of the intrinsic (tensile) strength of the peat lies. See section 4.2
Changes in topography	Slight changes in topography can result in changes in peat strength due to peat thickness, groundwater & peatland vegetation
Quaking (Buoyant) peat	Common in flat areas and is indicative of highly saturated peat with low strength
Bog pools	An indicator of areas of weak, saturated peat. Commonly open areas of water within peat are interconnected, with the result that there may be sub-surface bodies of water with low strength peat present around the perimeter of such features
Drainage	Drained peatland will typically result in an increase in peat strength. Poorly drained peatland can allow softening of peat.

It is not possible to account for all changes in peat strength by visual indicators alone. Adequate ground investigation is essential prior to design and construction to determine the extent and characteristics of peat (Munro, 2004). In addition to the characteristics of peat, the possible presence of an underlying soft soil beneath the peat needs to be investigated. Such a layer has been linked with previous cases of peat instability and failures and most commonly occurs where lacustrine deposits are present beneath the peat which has formed in a basin/topographical hollow.

Intrusive ground investigation for access tracks in blanket peat would typically comprise peat depth probing, field vane testing, physical sampling (e.g. gouge core augering or window sampling) and trial pitting. The above intrusive investigation methods, with the addition of suitable laboratory testing, allow the main parameters of peat and the underlying material to be determined.

A comprehensive ground investigation would allow a detailed design to be completed and is considered essential prior to construction works (Scottish Renewables et al, 2015). The findings of a ground investigation would also be used to produce a site specific risk assessment.

Prior to construction, a site specific risk assessment should be carried out by the contractor (MacCulloch, 2006). A comprehensive risk assessment will ensure all risks have been identified and the appropriate measures are in place to reduce the risks and impacts to an acceptable level.

A detailed design of a floated access track, using comprehensive ground investigation data, will provide the optimum make-up including granular fill thickness, reinforcement (geogrid and geotextile) and any other construction requirements.

The in-situ ground conditions will determine the make-up of floated access tracks, however certain areas may need to be avoided completely based on geotechnical or non-geotechnical related constraints. Any areas with an elevated risk should be identified prior to construction with a comprehensive site reconnaissance and ground investigation.

Micro-siting of proposed infrastructure elements such as access track routes where variable peat thickness and strength is present should be considered. At present within Ireland the planning guidelines allow minor movements for the infrastructure of up to 20m following the granting of planning permission for a wind farm development (DoEHLG, 2006).

End tipping of construction material directly onto peat resulted in an impact loading which contributed directly to the bearing failure beneath the access track and the large-scale peat failure at Ballincollig Hill. A reduction in the rate of construction could be adopted in elevated risk areas when constructing floating access tracks. This would involve loading the surface of peat slowly to allow the underlying peat to respond to the increasing load and be given sufficient time to consolidate and gain strength rather than shear. The use of partially laden dump trucks and the method of spreading the load upon tipping over a greater area could be considered.

Construction should be supervised by suitably competent personnel, experienced in floating access track construction techniques and working in peatland areas (MacCulloch, 2006). The contractor should ensure that the risk management plan is adhered to and that control measures are in place to ensure that mass peat instability/failure is not likely as a result of the works. The contractor is also responsible for developing the risk management plan as the works progress where previously unforeseen risks are identified and suitable measures are put in place. The adoption of a certificate/permit to work scheme whereby an inspection and approval for each section of access track is required prior to work proceeding on another section of track is advised.

Continued monitoring of floated access tracks post construction should be carried out to detect any settlement issues or signs of local or mass instability within the peat.

In addition, the identification of suitable emergency measures to be implemented in the event of a peat failure to restrict the flow of peat and limit the damage to the surrounding environment is essential for any construction works in peatland areas (Dykes and Jennings, 2008).

6 CONCLUSIONS

The following conclusions are given:

(1) A peat failure occurred at Ballincollig Hill wind farm on 22 August 2008 which coincided with the construction of a floated access track.

(2) The failure comprised a translational slide of peat followed by a peat flow as the mass moved downslope.

(3) The total failure volume of peat was estimated at about 120,000m^3.

(4) A number of factors are considered to have contributed to the failure including the construction of a floated access track, extensive mechanically cut peat for the purpose of peat harvesting, rainfall retained within the mechanical cuts and the presence of weak peat.

(5) In order to reduce the potential of peat failure during the construction of floated access tracks or similar works, a number of lessons learned are given.

   a) A comprehensive site reconnaissance should be carried out. Peat characteristics can be spatially variable which can result in localised changes in strength. A number of imperative visual indicators of change in peat strength should be taken into account.

   b) Adequate ground investigation is essential to determine the extent and characteristics of the peat.

   c) A site specific risk assessment, micro-siting of infrastructure elements, reduced rate of construction in areas deemed with an elevated risk, engagement of competent personnel should be undertaken.

   d) In addition monitoring both during and post-construction and identification of suitable emergency measures in the event of a peat failure should be adopted.

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