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Assessment of peat slides and failure mechanism of blanket peat at Flughland, Ireland

Évaluation des glissements de terrain de tourbe et du mécanisme de rupture de la tourbe à Flughland, Irlande

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ABSTRACT: The Flughland site located in County Donegal on the northwest coast of Ireland experienced multiple peat slide events following an intense frontal rainfall event in August 2017, which caused extensive flooding and landslides in the region. Investigations into the cause of particularly peat slides and the risk to the site was carried out shortly following the event. The ground conditions at the site consisted of blanket peat about 1m thick overlying mixed glacial soils and weathered to intact rock. The failure mechanism comprised a translational slide with the basal shear surfaces dominantly within underlying glacial soils. The investigations found evidence of previous instability and partially re-activated relict failures. The paper includes an assessment of the likely return period based on rainfall intensity and compares the identified failure mechanisms with other well-known peat slides.

RÉSUMÉ: Le site de Flughland, situé dans le Département Donegal, sur la côte nord-ouest de l'Irlande, a connu de multiples glissements de terrain à la suite de pluies frontales intenses en août 2017, qui ont provoqué de graves inondations et glissements de terrain dans la région. Peu de temps après l'événement, des enquêtes ont été menées sur la cause des glissements de terrain et sur les risques pour le site, en particulier les glissements de terrain. Les conditions du sol sur le site consistaient en une tourbe de couverture d'environ 1 m d'épaisseur recouvrant des sols glaciaires mixtes et altérés par les intempéries jusqu'à des roches intactes. Le mécanisme de rupture comprenait un glissement en translation, les surfaces de cisaillement basal étant dominées par les sols glaciaires sous-jacents. Les enquêtes ont permis de trouver des preuves d'instabilité antérieure et de réactiver partiellement les défaillances reliques. L'article comprend une évaluation de la période de récurrence probable en fonction de l'intensité des précipitations et compare les mécanismes de défaillance identifiés avec d'autres glissements de terrain bien connus.

Keywords: blanket peat; landslide; rainfall; Donegal.

1 INTRODUCTION

On 22 August 2017 an intense rainfall event in County Donegal in northwest Ireland caused extensive flooding and numerous landslides causing damage to homes with an estimated 1500km of road network affected (Maguire, 2017). Following the rainfall event, an inspection of an upland site (about 3km^2) within the Flughland valley (Figure 1) in the affected area was carried out to assess the extent and characteristics of the landsliding, and the impact and risk of further landsliding. The paper

includes an assessment of likely return periods and compares the identified failure mechanism of the recent slide events with other well-known peat slides.

2 TOPOGRAPHY

The affected site is within an upland valley located between Leamacrossan Hill (392m OD) to the north and the Glackmore Hill ridge line (362 to 397m OD) to the south (Figure 1). The upland valley forms the headwaters of the Meenatomish River with the valley floor at an elevation of about 250 to 280m OD. The surrounding slopes rise at 10° up to about 25°. The Meenatomish River and a public road are located along the northern part of the valley floor. Wind farms are located on the higher ground to the north and within the valley floor.

Landslides occurred on the relatively steep slopes surrounding the valley floor to the north and south and effected the public road and local electricity services. A number of the landslides originated in the headwater areas of these streams, with other landslides occurring within relatively open slopes.

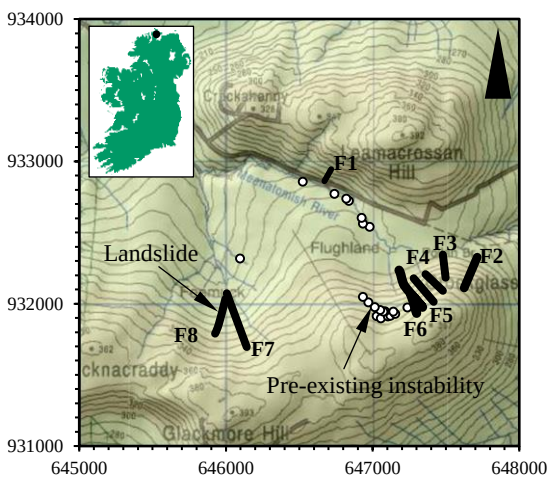

Figure 1. Topographical location of site showing landslide locations (base GSI, 2018)

3 GROUND CONDITIONS

The upland valley site is essentially covered with blanket bog. The typical peat depth varied from several metres within the valley floor with decreasing peat depth on the steeper slopes. Typically, peat depth on the slopes was less than 1m but locally reduced where steeper ground was present.

Below the blanket peat the ground conditions were variable comprising glacial soil, head deposits and weathered to intact rock. The underlying rock comprised Dalradian dark pelitic and psammitic schist, which was generally at shallow depth on the slopes with occasional exposures.

4 RAINFALL & LANDSLIDES

The rainfall event that affected the northwest of Ireland on 22 August 2017 started as a tropical depression (Gert) on 13 August before reaching hurricane force off the Atlantic coast of North America (NHC, 2017). As Gert moved across the Atlantic it reduced to a post-tropical storm and subsequently a low-pressure system, which made landfall in the northwest of Ireland in the afternoon of 22 August bringing extremely heavy and localised rainfall to north Co. Donegal (Figure 2).

The month of August 2017 was notably wet in north Co. Donegal. At the nearest long-recording weather station to the site (Malin Head located about 17km north) the daily rainfall recorded on 22 August was 77.2mm, which was about 45% of the monthly total. This was the second highest recorded daily rainfall at the station since records began (in 1955) and the highest August daily rainfall (Met Eireann, 2018).

A comparison with the highest daily recorded rainfall at the station (80.6mm on 5 December 2015 during storm Desmond), in which no landslides were recorded in the area, is shown in Figure 2. The comparison shows that the hourly rainfall intensity on 22 August 2017 was notably

greater than that recorded on the day of the highest rainfall.

On 22 August, about 50mm fell in a 4-hour period. The hourly rates from 19 to 20:00 hours of 16.4 and 16.6mm/hr were the highest recorded at the station (since hourly records started in 1988) with the next highest falling a few days before on 17 August 2017. Clearly, the short-duration rainfall intensity was significant in initiating landsliding.

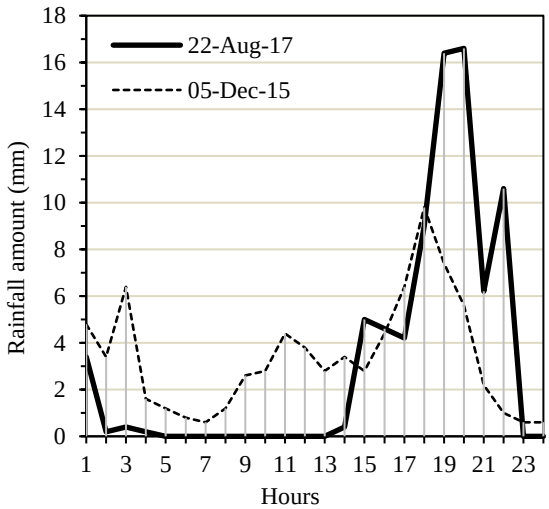

Figure 2. Hourly rainfall data (Met Eireann, 2018)

In north Co. Donegal the monthly rainfall averages vary from about 60 to 120mm, with broadly more rainfall occurring in the months October to January. However, rainfall intensity (mm/hr) is greatest from July to September. The higher intensity hourly rainfall amounts per month over about a 30-year period are shown in Figure 3, which clearly shows that August has a notably greater intensity of hourly rainfall; though the probability of such rainfall intensity is very low.

The high intensity hourly rainfall from July to September is likely related to greater storm activity during these months. A review of peat failures in the UK showed that there was a higher frequency of occurrence in July and August, which was similarly related to greater intensity rainfall (Warburton et al, 2004).

Antecedent daily rainfall amounts were also significant preceding the rainfall on 22 August. The 7 to 28-day antecedent rainfall amounts are within the upper 0.05% of rainfall data for the last 60 years.

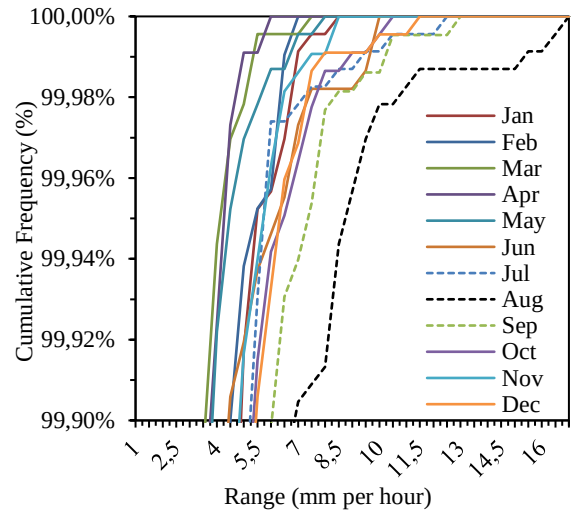

Figure 3. Hourly rainfall intensity for each month for 30-year period (Met Eireann, 2018)

With respect to landslide initiation, generally high intensity short-duration rainfall is associated with shallow landsliding and longer duration rainfall periods associated with deeper landslides (Postance et al, 2018). In Scotland, debris flows such as peat failures tend to be initiated following periods of heavy antecedent rainfall with subsequent high intensity hourly rainfall rates from about 10 to 75mm/hr (Winter et al, 2005). A similar rainfall pattern of preceding high antecedent rainfall and particularly high intensity hourly rainfall rates occurred on 22 August 2017 in north Co. Donegal.

High intensity rainfall events triggering particulalry peat failures in Ireland have been reported numerous times, most recently Dykes & Kirk (2001), Long & Jennings (2006).

It is recognised that whilst the rainfall station was only 17km north of the site, the rainfall at the site may be significantly greater due to localised

orographic effects. For example stations within about 5km of the site (which had only limited recoding facilities) recorded rainfall of 85.3 to 87.4mm on 22 August 2017.

5 LANDSLIDES

5.1 General

There were no previous landslides recorded in the area (GSI, 2018). Nevertheless, inspection of the site showed pre-existing instability, such as pre-existing tension cracks, slumps, partially displaced peat likely representing re-activated relict failures (Figure 1).

During the recent rainfall event 8 landslides occurred within the site with failure volume ranging from 840 to 8,400m^3. The landslides essentially comprised peat and a portion of the underlying glacial soil. A summary of the landslide characteristics is given in Table 1.

Table 1. Summary data of landslides

No.	L (m)	D (m)	W (m)	I (º)	Vol (m^3)
F1	60	0.7	20	10 to 22	840
F2	300	0.5	30	19	4,500
F3	150	0.4	20	25	1,200
F4	200	0.6	20	20	2400
F5	200	0.6	30	20	3,600
F6	350	0.6	40	20 to 22	8,400
F7	400	0.6	30	8	7,200
F8	350	0.7	30	10	7,350

L: length, D: depth, W: width, I: inclination, Vol: volume

The landslide mode of failure comprised initial shallow translation sliding of mostly peat which degraded downslope into a debris slide. The landslide failure mass mostly remained relatively intact throughout its travel except where channelised (F1). Typical length-to-width ratio was from 3:1 to 12:1, which is typical of debris slides (see Hutchinson, 1988).

The landslides were clustered, and in some cases, there was little intact ground between landslides (F2 to F6) see Figure 4. Landslide F1 blocked the local road, the remaining landslides occurred in open county and had no impact on infrastructure.

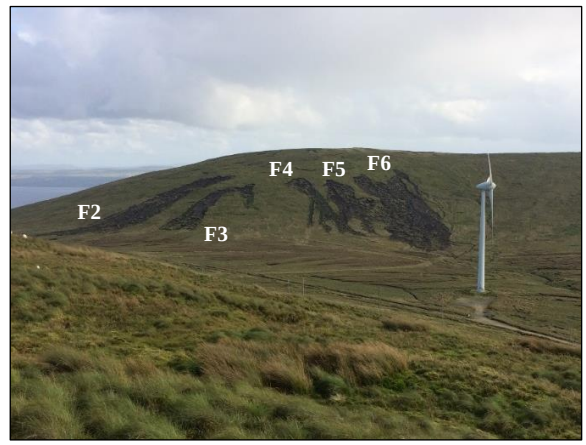

Figure 4 General view of landslides F2 to F6

F7 and F8 occurred in the headwaters of streams within notably open and relatively uniform slopes with gentle gradients (less than about10 degrees), see Figure 5.

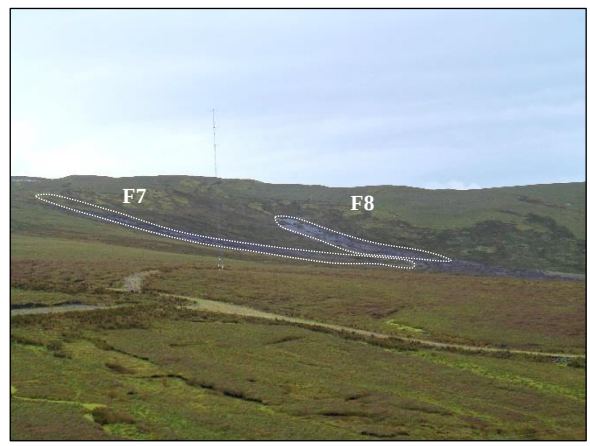

Figure 5 General view of landslides F7 to F8)

5.2 Shear Failure

The dominant material within the landslides was peat. Peat was described as generally soft dark brown pseudo-fibrous to fibrous PEAT with

thickness of about 0.4 to 0.7m. Inspection of the basal failure surface showed very little smearing or indication of shearing of peat. Though the landslides are referred to as peat slides this is essentially because peat was the dominant material within the landslides.

The basal shear surface was either at the interface of the peat and underlying soil or below the peat within the underlying glacial soil. Failure within the soil below the peat has been recorded at a number of peat slides, see Boylan et al (2008).

The basal shear surface typically corresponded to an horizon where there was a permeability contrast (aquiclude), at or below the base of the peat. At this horizon there was seepage with signs of localised preferential flow paths, such as natural pipes. The aquiclude essentially retarded downward migration of water which caused a build-up of water pressure at or just below the peat. A summary of the basal shear surfaces is given in Table 2.

Table 2. Summary of basal shear surfaces

Interface	Description
Within peat	• None recorded
Interface of peat and underlying soil	• Black hard pan layer (c.10mm thick) • Weathered/intact rock surface • Soft grey clayey SILT with minimal coarse content. • Firm grey gravelly to very gravelly clayey SILT
Below base of peat	• Typically, 0.1m below base of peat where: Above 0.1m soft to firm grey gravelly sandy clayey SILT, and below 0.1m firm grey gravelly to very gravelly sandy clayey SILT

At a number of the landslides, the basal surface comprised a discrete black hard pan layer at the interface of the peat and underlying glacial soil (Figure 6). This layer was likely an accumulation of soluble humic colloids leached over time from the peat above and cemented to the underlying soil. The layer provided a discrete plane of sliding and was essentially impervious and acted as an aquiclude. A similar hard pan was noted at the site of rain-induced peat slides at Pollotomish in 2003 (Boylan et al, 2008).

Figure 6. Black hard pan below failed peat (F2)

Other interfaces at the base of the peat included weathered/intact rock, soft silt layer, or firm silt layer which represented the upper surface of soliflucted material. All of which would have acted as an aquiclude. The soliflucted material clearly showed a characteristic macrofabric with clast long-axes aligned in a downslope direction parallel to the direction of flow.

Failure below the peat typically occurred about 0.1m below the base of the peat within glacial soil. Inspection of the glacial soil generally showed a sandy gravelly material within a silt dominant matrix with a progressive increase in strength/density with depth. The basal failure horizon was not discrete, unlike at the peat interface, and likely represented a partly indurated layer that was possibly associated with a process of leaching/cementation of soil particles that preceded development of the blanket peat (Schaffhauser et al, 2017).

5.3 Landslide Failure Mechanism

The landslide failure mechanism comprised the following key stages:

(1) Ingress of surface water below the shallow peat surface. Water entered the ground along

preferential flow paths such as existing stream gulleys, peat cutting or fissured peat. The heads of F1 to F6 were located at the crest of slopes where slope curvature, and likely fissuring in peat, was greatest.

(2) Downward movement of water within the ground was prevented at shallow depth due to the presence of more impermeable layers (aquicludes), which typically corresponded to the interface of the peat with the glacial soil, or more indurated horizons in the glacial soil, or where bedrock was at shallow depth. At these horizons, which represent the natural sub-surface drainage pathways, groundwater flowed parallel to the horizon, which was essentially parallel to the slope surface. Inspection of these horizons showed signs of seepage and natural soil pipes, which are assumed to be pre-exist the recent failures.

(3) The blanket peat which mantles the slopes has a notably low permeability, typically about 10^{-9}m/s (Jennings et al, 2015). The peat essentially provided a capping layer that allowed the build-up of a confined water pressure at shallow depth in the slope. The peat cover would have greatly increased water pressure particularly towards the down-slope end of the failure producing artesian conditions. This resulted in ‘blow-holes‘ forming in the lower part of the slope, as water escaped.

(4) The high intensity rainfall would have ensured that significant volumes of water entered the slope, which would have rapidly inundated the natural sub-surface drainage paths along the aquicludes.

(5) The build-up of water on the aquicludes would have increased water pressure at shallow depth causing a reduction in effective stress and subsequent loss in shear resistance causing sliding failure. It was previously observed that for rain-induced landslides in this type of peat terrain that the most common location for the basal shear is at the peat interface or in the soil below the peat (Jennings & Kane, 2015).

(6) Beyond the areas of recent landsliding there were signs of partial reactivation of pre-existing instability, such as multiple tension cracks (Figures 1 and 5). The failure mechanism that initiated this instability was undoubtedly similar to the above, but there was insufficient destabilising forces to cause full mobilisation of the peat. It is uncertain to what extent this relict instability existed prior to the recent rainfall event. In the face of a similar rainfall event, the presence of particularly pre-existing tension cracks could facilitate slope drainage and mitigate against potential build-up of excess groundwater, which could act to reduce the occurrence of similar rainfall-induced landslides. The presence of tension cracks though could increase erosion of the blanket peat.

6 CONCLUSIONS

The main conclusions are as follows:

(1) On 22 August 2017 an intense rainfall event in northwest Ireland caused extensive flooding and numerous landslides.

(2) About 50mm of rain fell in a 4-hour period with hourly rainfall rates up to 16.6mm/hr. These were the highest hourly rates recorded at the station (records started in 1988), and suggest a return period of at least 30 years.

(3) The short-duration hourly rainfall intensity was significant in initiating landsliding.

(4) Inspection of the Flughland valley site (Figure 1) within the affected area was carried out to assess the extent and characteristics of the landsliding, and the impact and risk of further landsliding

(5) Within the site, there were 8 landslides with failure volumes up to about 8,400m^3 and failure lengths up to about 400m. The landslides comprised initial shallow translation sliding which degraded downslope into debris slides.

(6) There were no previous landslides recorded in the area, though inspection showed evidence of pre-existing instability, that was partly re-activated during the rainfall event.
(7) The basal shear surface of the landslides was either at the interface of the peat/underlying soil or below the peat within the underlying glacial soil, and corresponded to distinct aquicludes within the soil profile (Table 2).
(8) The basal shear surface showed no/little shearing through peat. The landslides are referred to as peat slides essentially because peat was the dominant material within the landslide.
(9) Landsliding was initiated following a build-up of water on the aquicludes that increased water pressure causing a reduction in effective stress and subsequent loss in shear resistance causing sliding failure.
(10) A risk of a similar pattern of rainfall would likely result in further landsliding and possible reactivation of relict failures. The affect of particularly pre-existing tension cracks could mitigate against build-up of excess groundwater, which could potentially act to limit the occurrence of similar rainfall-induced landslides in this area.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

Boylan, N., Jennings, P. and Long, M. 2008. Peat slope failure in Ireland. *Quarterly Journal of Engineering Geology and Hydrogeology*, **41**, 93–108.

Dykes, A.P., Kirk, K.J. 2001. Initiation of a multiple peat slide on Cuilcagh Mountain, Northern Ireland. *Earth Surface Processes and Landforms*, **26**, 395–408.

Geological Survey of Ireland (GSI). 2018. GSI Spatial Resources Public Data Viewer: http://dcenr.maps.arcgis.com/apps/MapSeries/index.html?appid=a30af518e87a4c0ab2fbde2aaac3c228

Hutchinson, J.N. 1988. General report: morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. *Proceedings of the 5th International Symposium on Landslides, Lausanne*, **1,** 3–35

Jennings, P. & Kane, G. 2015. Geotechnical engineering for wind farms on peatland sites. *Proceedings of the XVI ECSMGE Geotechnical Engineering for Infrastructure and Development*, 595–600.

Jennings, P. & Kieran, P., Gill, M. and Johnston. T. P. 2015. Use of peat as an engineering material: an engineering case study. *Proceedings of the XVI ECSMGE Geotechnical Engineering for Infrastructure and Developmen*t, 2553–2558

Long, M. & Jennings, P. 2006. Analysis of the peat slides at Pollatomish, County Mayo, Ireland. *Landslides, Journal of the International Consortium on Landslides*, **3**, 51–61.

Maguire, S. 2017. Over 300 parts of Donegal road network damaged by floods. *The Irish Times*, 28 August 2017.

Met Éireann. 2018. *Historical rainfall data*. https://www.met.ie/climate/available-data/historical-data

NHC. 2017. *Hurricane GERT advisory archive*. National Hurricane Center, National Oceanic Atmospheric Administration. https://www.nhc.noaa.gov/archive/2017/GERT.shtml?

Postance, B., Hillier, J., Dijkstra, T. & Dixon, N. 2018. Comparing threshold definition techniques for rainfall-induced landslides: A national assessment using radar rainfall. *Earth Surf. Process. Landforms*, Vol. **43**, 553–560.

Schaffhauser, A., Payette, S., Garneau, M. and Robert, E. C. 2017. Soil paludification and Sphagnum bog initiation: the influence of indurated podzolic soil and fire. *Boreas*, **46**, Issue 3, July 2017, 428–44

Warburton, J., Holden J. & Mills, A.J. 2004. Hydrological controls of surficial mass movements in peat. *Earth-Science Reviews*, **67**, 139–156.

Winter, M G, Macgregor, F. & Shackman, L E. 2005. *Scottish road network landslides study*. The Scottish Executive, Edinburgh.