Peat Failure in Ireland
A review based on three different case studies.
Brendan McCourt 950113-T156/40104794
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Abstract

The main objective of this thesis was to determine how and why peat fails with the aim of reducing the threat caused by this and preventing its occurrence. Peat is a very common soil in both the UK and Ireland so knowing how it fails and how to prevent it is hugely beneficial. To do this 3 separate case studies where looked at, all located in Ireland but in different areas, to see if the failure methods had any similarities or differences that could be linked together. The main finding was that there was not one sole causal factor for all peat slide but instead a combination of factors; although some factors were more influential than others for example rainfall. A number of solutions were put forward such as a drainage system for the peat slopes, and while they are limited, due to most of the factors being of natural origin, they have the potential to reduce the likelihood and frequency of failures if properly implemented.

Introduction

Peat is described as an accumulated heterogeneous mix of decomposing plant situated in a oxygen deficient, water saturated environment (International Peat Society, 2017). Peat bogs in total cover 1.34x10^6 hectares throughout Ireland this is in total 16.2% of the countries entire surface, with in the Republic 17.2% of the total land surface is covered and 12.4% in the North (Hammond, 1981). The most common use of peat bogs is to be harvested for their peat to be used in energy production, heating of homes and other uses, but when a construction project is due to take place in peat lands certain geotechnical problems can occur. The most harmful and common problem is peat failure; this is the method which will be investigated in this thesis, which can occur in three different forms:

- Bog Slides - An upper layer of peat slides over a lower more humidified layer.
- Peat Slide - A shallow transitional mass movement involving upland blanket bog.
- Bog Flow – Liquid based peat escapes from beneath the less humidified surface peat.

In total there has been over 70 reported events of peat failure in Ireland (Boylan et al., 2008), this figure is more than likely higher due to not all events being noticed and reported. It is important that why fully understand why peat fails because it takes up such a large proportion of the island. If we do not understand why it fails there is little that can be done to prevent it which will limit the future building/infrastructure prospects.

The objective of this paper is to analyse and discuss past peat failures in a literature review using the current papers written on the subject. It will also provide different solutions of how to minimize the problem using learned knowledge and experience and also guidance from previous failures. The literature review is based on three different papers:

1. Failure of peat-covered hill slopes at Dooncarton Mountain, Co.Mayo, Ireland: Analysis of topographic and geotechnical factors (Dykes and Warburton, 2008))
2. Initiation of a multiple peat slide on Cuilcagh Mountain, Northern Ireland (Dykes and Kirk, 2001)
3. Morphology and causes of recent past peat slides on Skerry Hill, Co.Antrim, Northern Ireland (Wilson and Hegarty, 1993)

Peat Properties

Peat is a highly complex, organically rich porous material, it is said to contain \( \geq 20 \text{ mass } \% \, C_{\text{org}} \) (Rezanezhad et al., 2016) which developed in the post glacial (Holocene) period. It has a high porosity, low bulk density which allows it to swell and shrink accordingly due to wetting or drying of the
material. In Ireland there are three different types of peat, which are Raised Bogs found in the Central Plain, Blanket Bogs of the Western Seaboard and upland regions and fen peats, all of which are found in areas of impeded drainage and/or high rainfall (Hammond, 1981). These can be further classified as Ombrogenous mires where the growth of the bog is from the effect of atmospheric precipitation, this includes raised and blanket bogs, and Topogenous mires where the growth is due to the surrounding topography and the ground water conditions, this relates to the fen peat.

**Raised Bogs**

- Complex Structure of organic debris with undrained thickness in the range of 9-12m.
- A basal tier of peat types formed under the influence of minerotrophic ground water.
- Sub-surface, upper tiers comprised of humified and poorly humified Sphagnum peat.

**Blanket Mire**

- Undrained thickness of 1-6m
- Homogenous in their morphology but can have 3 basic layers
- An upper fibrous layer dominated by recent and subfossil roots of cyperaceous plants.
- A sub-surface layer of pseudo fibrous peat.
- A basal layer of well humified, greasy peat with variable amount of timber remains.
- Remainder dominated by plants of grass or cyperaceous origin.

**Fen Mire**

- Fen Mires are found everywhere not just in the one location and comprise of liminic, telematics and terrestrial peat types.
- Occur at the base of raised bogs in the Central Plain, river valleys, poorly drained hollows and adjacent to raised bogs.
- Undisturbed fen mires are very uncommon as most have been drained and cultivated for industrial and commercial use.

Peat can then be sub divided into two different layers the acrotelm layer and the catolem (Dykes and Warburton, 2006). The acrotelm is the upper layer of bog peat it encompasses the area of active root growth and water table fluctuations that are season dependent. The catolem is then the lower layer of peat, it is often referred to as basal peat, it is much more humified than the acrotelm and does not contain any root growth or structures and can be described as biologically and hydrologically inert.

**Peat Failure Methods**

As previously mentioned in the introduction there are two main failure modes for peat. These are Bog Flow (commonly known as Bog Burst) and secondly Peat Slides. These two failures types are examined in more detail in this section.
**Bog Flow**

This is where large volumes of water and peat debris break away from the surface of the bog and follow the path of existing water surface channels down the slope. The peat is usually found to be highly saturated with water before failure occurs to an extent where it is in a near fluid like state, leading to a buildup of hydrostatic forces which are thought to be one of the main factors behind the failure (Boylan et al. 2008). It is mainly a problem that applies to raised bogs due it having upper fibrous layer over a lower body of weak amorphous peat which makes its extremely susceptible to this mechanism because of the differing internal strengths of the two layers.

**Peat Slides**

Where a mass of intact peat moves as one body down the failed slope, it is as a result of a discrete shear plane in the peat which is found at either the bottom of the peat or very close to it (Boylan et al. 2008). The failure being in the shear plane itself allows the peat to move as the one mass not in separate pieces as in Bog Flow although the further it continue to slide down the slope it will start to disintegrate into individual pieces due to the friction forces between the slope and the peat. Records indicate that it mostly affects blanket bogs (Mitchell, 1938; Dykes & Kirk, 2001).

**Bog Slide**

It is defined as “Failure of a blanket bog involving sliding of intact peat on a shearing surface within the basal peat” (Dykes and Warburton, 2007). The peat itself fails at a specific location, for example a large convex break of slope, the failure then continues to proceed up the slope as the peat continues to slide downslope. Smaller bog slides tend to occur on a steeper than average slope with a thin layer of peat and the entire segment fails instantaneously rather than a gradual deterioration of the slope.

**Classification Problems**

There are numerous problems in determining whether the failure was a burst or slide. Early accounts don’t distinguish between the two so to determine their failure mode is quite problematic and we can only use the information that was gathered at the time, it also makes the choice inaccurate. This reduces the amount of research available on the topic and leads to a degree of inaccuracy in today’s classifications. Some Bog Flows are likely to have originated from a shear failure on a discrete sliding surface, not unlike a peat slide, before breaking into slurry. This is due to a loss in the mass strength of the material which is a result of a disturbance, for example an anomaly like a large rock on the failure slope, and then developing into flow an example would be the Knocknageeha Bog failure in 1896 (Dykes and Warburton, 2008). Another more recent example would be the Derrybrien failure in 2003; through investigation it was found that the failure surface was located at the bottom of the peat layer roughly 200-600 mm above the mineral soil, as according to the peat slide criteria. But although the ground initially moved as the one mass it later broke down substantially until it acted as a flow-type substance. These circumstances mean that the failure should be classified as a bog flow not a peat slide as the initial shear failure would suggest (Lindsay and Bragg, 2005).

Dykes and Warburton (2006) developed their own classification system, to try to find a solution to this problem, with six different failure types based on a number of failure and morphological conditions. A key point of the paper is that apart from Peat Flow the nomenclature of the failure modes has no set standard, as the names of each mode have been used interchangeably by each individual author meaning they rely more on the description of the failure to properly describe the specific cause of each event. The failure categories are as follow Bog Burst, Bog Flow, Bog Slide, Peat Slide, Peaty-debris Slide and Peat Flow. In this classification system Dykes and Warburton have separated Bog Flow and Bog Burst unlike Boylan (2008) which had them listed as the same failure; this again is simply down to the different naming systems from different authors. The two extra modes that are suggested in this paper are as follows:
**Peat Flow**

According to Dykes and Warburton (2007) this is the one failure mode that is named interchangeably by different authors, it is defined as “Failure of any other type of peat deposit (fen, transitional mire, basin bog) by any mechanism, including flow failure in any type of peat caused by head-loading”. This is the most uncommon type of peat failure with only four known and recorded failures in total. It can then be suggested that this description is likely to change when more failures occur as there will then be more evidence and data to study, where as if now the amount of data is limited due to the infrequency of it.

A table was drawn up in Dykes and Warburton (2007) which simplified the failure methods and their categorization, it is displayed below.
Possible Causal Factors

The most likely and most cited factor in all peat failures is high intensity rainfall and periods of prolonged rainfall, this can be said to be because of the saturation of the peat leading to a decrease in shear strength of the material (Boylan et al, 2008). An additional causal factor to this scenario is a period of hot and dry weather beforehand, for example a hot and dry summer before a very wet autumn and winter would be the ideal conditions for a peat failure to occur. This is due to the shrinkage and cracking of the peat in the dry period thereby weakening and damaging its structure before the oversaturation caused by the heavy rainfall in the autumn/winter period.

The effect of sudden loading on peat can be very detrimental and can initiate a bearing failure below the loaded area; this in turn leads to the creation of a shear plane within the peat mass under the loaded mass and between the peat layer and the mineral substrate (Boylan et al, 2008). The shear plane causes the peat to loses strength and as it begins to fail and slide down the slope the active pressure on the peat downslope only increases thereby having a knock on effect of continuing and enhancing the failure.

The excavation of peat both naturally, by stream undercutting, and unnaturally, by man-made excavations, both lead to a weakening of the peats structure and therefore increasing the risk of a peat failure. Although as described in detail later namely in the Dooncarton Mountain case study (Dyes and Warburton, 2008). They are not the sole cause of failures, they cause failure by combining with other causal factors and are not enough to cause a failure on their own.

Peat failures have generally been recorded as lying on a slope of between 4-8° gradient (Boylan et al, 2008). It is postulated that this is because this slope angle allows the peat to build up over time leading to instability developing whereas on a steep slope only a thinner therefore more stable layer will form. This is described in Mitchell (1938, p.54) “in all cases where bursts in mountain bogs have been investigated there are indications that growth had rendered the bog unstable, and that the burst acted as a safety valve to restore equilibrium”. The shape and structure of a slope can also be a contributing factor in failures, a slope with a convex break in it is likely to be involved in a failure, and this will be demonstrated in the following case studies. It is thought that this shape of slope leads peat to be of a much thicker depth with a higher level of ground water just above the break with then a thinner, drier layer of peat below. When a failure then occurs at the break the thin, dry layer offers little resistance to the thicker layer above leading to a progressive failure up the slope. Concave slopes are also susceptible to failure but in this case the mechanism is quite different the upper layer of peat is thought to slide over the lower layer because of a tearing at the base of the ridge this then further evolves to complete the failure. The ridge forms to begin with because of the concave shape up the slope which of course means this failure mode is unique to this type of slope.

The hydrological and geological conditions that lead peat to form poignantly can also be one of the more likely reasons it fails. For peat to form the land has to be waterlogged this usually happens where there is has been a depression or where a water channel flows through an area. The land then starts to decompose and humidify creating peat but as the decompositions continues the peat will in turn start to lose some of its strength making the material more at risk of failure. With the permeability of the catolem layer of peat being quite low (Boylan et al, 2008) the peat then needs another way of transporting flowing ground water it does this through both macropores and natural water pipes throughout the peat. As can be seen in the following case studies the presence of the natural pipes at failure sites seems to be a significant factor in the failure this is thought to be due to the erosion and weakening of the peat around the pipes by the flowing water therefore contributing to the failure.
The peat-mineral interface can be an important factor in a failure mechanism, particular shown in the Dooncarton Mountain case study (Dyes and Warburton, 2008). Using this case study as an example an iron pan underlay almost all of the failure sites it was covered in an impermeable, slip resistant mineral that caused water flow to increase downslope eroding the lower layer of peat, decreasing its strength and causing it to fail. This shows that an unideal peat-mineral interface combination can enhance negative effects on certain ground conditions for example ground water and therefore have an impact on the structural integrity of the peat.

Case Study 1 – Dooncarton Mountain, Co. Mayo

Pre-failure conditions

The event that occurred on Dooncarton Mountain on 19th September 2003 was quite large in its magnitude. A total of 40 peat landslide occurred in an area of 2.5km² (Dyes and Warburton, 2008). On this mentioned day a thunder storm hit the area of the mountain leading to a massive amount of concentrated rainfall in a relatively short period of time. An average of 90 mm of rainfall fell in the space of only 90 minutes with the heaviest rainfall being 110 mm in that time making this storm abnormally large (Dyes and Warburton, 2008). The weather conditions leading up to this day were an extremely wet May/June followed by a very dry August and a wetter than average September, 122% in the first 18 days. As previously mentioned in the casual factors section of this report these are the ideal lead up conditions for a peat failure with a very dry period that could potentially lead to shrinkage and cracking of the peat followed by a wetter than average few weeks and finally a bout of extreme rainfall in a very short period of time.

The main peat blanket on the mountain had been subjected to peat extraction in several places and there was some localized erosion and gulley development on two of the ridges although most of the peat was said to be relatively intact. There was an Inver Schist formation underlying all the failure slopes with blanket peat up to 2 m thick covering the upper ridges but this layer of peat rapidly decreases as it moves further downslope. It gives way to a thinner layer of peaty soil on the steeper scarp slopes. The failure was thought to be caused by extremely adverse hydrological conditions rather than integral weaknesses and faults in the slope itself, discontinuities in the slope such as boundary ditches and the man made peat extraction to name a few were not thought to be major factors but possibly did play a small apart in the failures that occurred.

How the site was investigated

This case study follows the analysis and investigations carried out by Dykes and Warburton (2008) that took place on 27-28th September, initial site investigations and early December. Because of there was such a large number of actual failures only seven where chosen to be investigated, they were selected so they encompassed the widest range of slope failures.

The slope profiles of each individual failure was measured using a gradient distance survey and the peat and mineral profiles of the failure scars were recorded for analysis. The wet-dry bulk density, ash and water content, particle size distributions and element chemical constituents needed to be determined, to do this monolith samples were retrieved from the head of the failures on the peat profiles and there were two other samples taken from non-failure sites to act as the control. The horizontal and vertical saturated hydraulic conductivities of both the peat and substrate materials were determined using the constant head method, the measured flow rate of water through a column of cylindrical saturated soil under a constant pressure difference. Intact blocks of material were extracted for shear strength determination, basal peat samples were obtained and exposed failure material was collected. These three sets of samples were subjected to standard saturation, consolidation then shearing procedure, using normal loads, intended to reflect the rapid development of the first time failures as shown by the morphological evidence gathered.
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The Factor of Safety (FOS) of the peat slopes were obtained using the Morgenstern-Price Method, a general method of slices developed using the theory of limit equilibrium to determine the different planar forces acting on each individual block. The effect of a sharp slope convexity on the aforementioned FOS was simulated using a simple topographic model of the Dooncarton hill slopes. A computer software program called SLOPE/W was used to analysis the stability of the slopes.

**Investigation findings and analysis**

Stability analysis found that the majority of the landslides occurred in the vicinity of a distinct slope convexity where the thicker layer of blanket peat changes to a thinner layer of peaty soil on the steep lower slope segments (Dykes and Warburton, 2008). In specific failure zones failure occurred over an iron pan near the base of the almost cohesionless soil horizon, shown in Fig 1. The iron pan was covered discontinuously a hard black material that may have been cemented soil horizon and corresponds with dopporite. This material provided a low friction surface for the soil to slide over, in comparison to the sandy soil material. This iron pan also created an impermeable layer that channelled any rain or excess water downslope increasing the derogatory effects of downslope water channels and pipes on the peat structure, one of the main causal factors of the peat slide failure mechanism.

![Fig. 2. General soil profile for Dooncarton Mountain. Zones A-C define different soil slope relationships.](image)

The FOS values were slightly higher in one of the zones as it had a thinner cover of existing materials above the failure surface in this area leading to a smaller shearing stress capacity and lower hydrostatic water pressure. The combination of this and the extremely bad hydrological conditions brought on by the storm was the main trigger for the failures. As previously mentioned in the causal factors section of this report natural convexities in the slope where found at the sites were some of the failures occurred and thought to have been some of the main triggers for the failures combined with the bad hydrological conditions. Due to the low inclination of the slopes on Dooncarton there was an accumulation of peat leading to an increase in the thickness of the layer and a decrease in the strength and stability of it. This was in fact a limiting factor for the failures as the steeper slopes with thinner layers did not fail with the others. In one of the locations the two of these conditions combined where there was an accumulation of peat above a convexity making it extremely susceptible to failure as it did.

In the areas where peat extraction had taken place the tine cuts had started to act as natural water channels providing a quick low resistance pathway for the excess water through the peat slopes into the weathered sand below. Horizontal discontinuities in the basal peat such as thin layers of mineral particles have a similar effect to the tine cuts also acting as a hydrological pathway for excess seepage therefore they both were complicit in lowering the overall strength of the peat mass making more
prone to failure. In saying this in (Dykes and Warburton, 2008). They found that the tine cuts and boundary ditches in 3 separate locations were not as important as originally thought in respect to the peats failure they found that the slopes were equally unstable throughout and so therefore it could have failed at any or every point not merely when the tine cuts and boundary conditions crossed the slope. At other failure conditions the failure was seen to occur at the point where the boundary ditches crossed the slope, from this the authors deduced that while the boundary ditches and tine cuts that are located on a particular slope cannot induce a failure by themselves but with the added instability from say natural pipes underlying the surface peat, causing hydrological problems, they were able to initiate a slope failure.

A number of retrogressive failures where found throughout the mountain range. At these failure sites there was found to be no continuous iron pan underlying the peat therefore they reasoned that the iron pan had no hydrological influence in the failure mechanisms at these locations. Although they did find extensive seepage at the peat-mineral interface which led to erosion by excess pore water dissipating through. This suggests that at the peat-mineral interface there might have been a high hydrostatic or possibly artesian pressure which in turn increase the pore water pressure in both the sand and the peat and that this might have been a common scenario on the upper slopes.

From certain studies carried out on some of the upper slopes, shear testing and slope segment analysis, it was found that some of the upper slopes should have failed long before they became fully saturated. This presents an unusual scenario and led the investigators to wonder why they had not failed previously and even why had they not failed under the storms adverse conditions. Two theories where put forward to try to satisfy this question firstly the slopes that did not fail were found to have had subsurface pipes and natural seepage which could drain the water at a faster rate than the cracks, macropores and other discontinuities could supply them. This made the drainage system of the peat effective and therefore stopped it from reaching saturation which creates a lot of instability problems in the peat slope. Secondly the thickness of the layers was said to be insufficient for failure to occur even when they did reach full saturation levels required. As the layers were thin they did not have the instability from the overburden pressure of the peat for failure to commence.

Summary

- Slopes that didn’t fail did so because they had insufficient thickness which provided them with enough stability to resist the failure even though full saturation had taken place.

- Slope segment analysis found that the upper convex shaped slopes were at the highest risk of failures.

- Tine cuts from peat excavation were found to be not as important as first thought but could present a problem by creating a pathway for excess water that in combination with any other factor could cause a failure. Boundary ditches were found to be insignificant in initiating failures.

- When boundary ditches where found with natural pipes in the clay layer below the peat they combined to cause a large peaty-debris slide (Dykes and Warburton, 2008). This implies that even though ditches are not able to initiate failures by themselves when paired with pipes they might be enough to make a previously stable slope unstable enough so that failure occurs.

- Slopes with subsurface pipes and seepage zones that were capable off draining the water faster than the macropores, cracks and other discontinuities in the peat slope could feed it kept the slope below full saturation level and therefore not have the induced stability problems that come with full saturation.

- A paradox is presented at the end of this investigation the presence of natural pipes at a peat failure site indicates that they are a casual factor in the failure of the slope (Boylan et al,
2008), but as they develop and expand under extreme hydrological loading conditions they can in fact lead to a better drainage system by having their capacities increased hence reduced the likelihood of full a saturation linked failure. This suggests that more investigation and work needs to be carried out on this subject to further enhance our understanding of the problem.

Case Study 2 – Cuilcagh Mountain

Pre-failure conditions

At an unknown time between 24-25th October 1998 a large multiple peat slide occurred on the northern side of the Cuilcagh mountain. The site was made up of blanket bog which was in the region of 2-3m deep locally, the peat had formed over a clay substrate of a variable thickness and an uncertain origin, which in turn is formed over a layer of Namurian shale and sandstones. A failure in the clay substrate layer underneath the basal layer of peat was determined to be the main casual factor behind the failure (Dykes and Kirk, 2001).

Over the period of 23-26th October there was an estimated rainfall of between 62.7-99.7 mm with a maximum intensity of 20 mm per hour. There had been no change in the average rainfall over the summer period compared to the previous years but there was a dry period of around 5 weeks prior to the failure event although it was not thought to have been significant enough to cause shrinkage and cracking weakening of the peat. The week in the lead up to the event had a rainfall of 80 mm throughout the entire week; again this was not thought to be substantial enough to cause any structural problems in the blanket bog.

How the site was investigated.

The failure site was first photographed on 26th October, the day after the failure was said to take place, the first preliminary surveys and samples were obtained and conducted between 29-31st October (Dykes and Kirk, 2001). These were followed by a detailed surveying and mapping and more field characteristics, peat and clay samples around one month later with the hydraulic conductivity of the peat being measured using piezometers.

The field saturated moisture contents, saturated and dry bulk densities, loss on ignition of peat and minerals were all determined using standard lab methods. Assumed relationships between water content and negative pore pressure for the mineral layers were calculated using the saturated hydraulic conductivity values and the relationships for materials with comparable characteristics. Because of this method and the fact that the relationships in peat in reality are very complex the results are considered to be very speculative and should be treated accordingly.

Modelling software was used to analysis the failure movement and it was based on 3 main components:

1. The ‘soil moisture characteristic’ curve for each material in the problem
2. Darcy’s Law
3. A governing differential equation, based on continuity, for the changing volumetric water content of each elemental volume in terms of the total head, H, and the hydraulic conductivity, k, in the x and y directions
Investigation findings and analysis

The failure slope had an inclination of $7^\circ$, within the typical range of $4-8^\circ$ for failure, with around $0.7\text{ m}$ of peat covering the mineral substrate below for the upper scar failure with another large failure $100\text{ m}$ downslope, both failures were considered peat slides (Dykes and Kirk, 2001). A total volume of $9100\text{ m}^3$ of peat and clay was calculated to have moved during the event from both the upper and lower scar, with $3400\text{ m}^3$ of this volume being from the upper scar failure. An outline of the multiple failure is shown in Fig. 3.

![Fig. 3. Outline of multiple peat slide on Cuilcagh Mountain. Arrow identifies the path of the lower erosion path. Datched lines indicate intact peat. Shaded are indicates displaced deposited peat. Narrow parallel lines indicate drains.](image)

Upper scar failure

The total length of this scar was found to be $75\text{ m}$ with a maximum width of $42\text{ m}$ near the head; the scar’s lower limit contains a drainage ditch which traverses the slope just above a convex break of slope. Another drainage ditch was present at the widest part of the scar prior to the failure event. The peat was fibrous, giving it a high tensile strength, and moderately decomposed and similar to the acrotelm layer of peat found elsewhere on the mountain range. The peat had formed above two different layers of clay, the upper layer (directly beneath the peat) was pale grey-brown clay of thickness $0.4-0.5\text{ m}$ which varied between clay and fibrous peaty clay and the lower layer was a dark, blue-grey sandy clay of thickness $1.5\text{ m}$. It was discovered that the failure occurred at the interface of these two clay layers around $1.1-1.2\text{ m}$ below the ground surface. The scar surface was stony and had some lumps of pale clay remaining, but with an overall smooth surface. Two small rafts and some small pieces of peat remained on the upper scar surface with larger rafts remaining intact further down the failure slope, indicating that the upper failure occurred using a sliding mechanism. The large intact rafts of peat are also consistent with its fibrous nature as it has higher shear strength therefore less likely to degrade into smaller blocks.

There were two distinct striations left on the scar surface it is likely that these were caused by boulders within the failed clay layer scouring the surface as they travelled downslope. They initially slid at $90^\circ$ to the upper drain and then turning to move down the steepest section of slope. This also indicates that the failure first started above the upper drain on the slope segment. Another indicator is the change of direction is directly linked to the rotation of a large raft on the western edge of the scar; the raft wouldn’t have had enough momentum to continue up onto the layer of intact peat below the upper drain. The last and most compelling indicator is that the intact peat rafts began to slide over the in situ peat on its eastern edge which could only have happened by a continuous driving mass applying a driving force from upslope.

The sphagnum species which was growing on the peat layer around the failure surface required a higher than average water content in the peat, it can then be implied that the peat must have had sub-surface piping to satisfy this increased water demand. Furthermore 5 small circular pipes were found in the clay layer beneath the basal peat, one of which was recorded discharging water up to four weeks after the event and two others discharging water at the peat clay interface. The plant species that is
growing below the ditch acts as a low friction surface allowing the peat rafts to easily move down the slope, the rafts continued to slide for 95m below the track, causing an erosion track, until the friction of the surface layer was enough to resist the movement.

**Lower scar failure**

The lower scar was larger in size with a total length of 80-85 m and a maximum width of 70 m, it lies on a slope of gradient 12° initially which reduces to 5° further downslope. It shares a lot of similarities with the upper scars but has a few important differences, mainly no pipes or ditches and more peat rafts left intact on the failure surface.

It was concluded from morphological evidence that the failure occurred in two stages. The sliding rafts from the upper scar failure are thought to have created large enough shear stresses in the slopes underlying peat structure to cause the failure and excavation of the lower erosion track. Then the reduction in toe support as a result of the peat failing caused a retrogressive failure of the steeper slope above. They are described as a multiple mass movement as the two failures must have occurred within roughly thirty seconds of each other.

**Mechanisms**

The FOS that was obtained from the initial stability analysis, assuming no pipes and drains, indicates that the failure would not have occurred in the absence of some other contributing factor (Dykes and Kirk, 2001). There was no residual evidence, when the site was investigated, that tension cracks were present in the peats structure prior to the failure event but it is thought possible that there could have been desiccated cracking from peat shrinkage during the previous dry periods. These in turn could have funnelled excess rainwater into the downslope areas of the peat, leading to the creation of subsurface pipes. It must be noted that tension cracks could not be accounted for in the stability analysis model so there would be a relative margin for error in the results.

From the model results it was seen that neither the tension cracks or reduced shear strength values were the cause of the failure, but they may have been contributing factors. When the clay was at peak strength with no tension cracks, a drain or pipes would not have reduced the clays strength enough so that it would fail. An effective drain would lower the ground water table, therefore reducing the internal pore water pressure; the overall effect on the peat would be to in fact lower the factor of safety as the lower edge of the peat mass would then be unsupported, according to the results from the stability analysis. The degraded drain causes a reduction in support without the reduction in pore water pressure due to the infilling of immature peat causing it to remain full of water.

The presence of subsurface pipes was found to influence the FOS in two ways:

1. If a pipe is filled by free flowing water from further upstream under certain runoff conditions, then the value of the FOS will be directly linked to the distance from the start of the pipe. The further upslope the pipe begins the greater the hydrological pressure applied from it therefore the lower the FOS.

2. The further the pipe extends into the failure zone, the quicker the FOS is reduced due to the artesian pressure being enhanced instead of being dissipated.

The size of the pipe was found to have had little effect on the 2D analysis but it was thought that it might have caused raised pore pressures between adjacent pipes in the clay.

**Summary**

- The condition of the peat was unlikely to be a direct factor since failure occurred almost 0.5m below the peat. The increased level of rainfall was thought to have been the main casual factor.
The location of the failure was found to be the interface between the two mineral layers underlying the peat, this acted as a structural weakness due to its lower shear strength capacity under adverse conditions. Due to this the failure was much deeper than had been originally reported in previous site reports.

The event wouldn’t have been exceptional if the drains had not been cut, seeing as they were the result was generally worse conditions. Making the cutting of the upper drain and its consequent degradation a major causal factor.

The influence of pipes was necessary with this degraded drain for the failure to occur.

The entire mass movement could have been initiated by the failure of the small slope segment above the upper drain due to a retrogressive failure.

Case Study 3 – Skerry Hill, Co. Antrim

Pre-failure conditions
At an unknown date in November 1991 two shallow landslides occurred on Skerry Hill in Co. Antrim, this area was adjacent to where slides had happened roughly 25 years previously. The area affected was made up of blanket bog which had been quite substantially negatively affected by erosion and peat harvesting, as is the general case for the Skerry Hill landscape. The peat has formed over a layer of tertiary basalts and Dalradian Schists (Wilson and Hegarty, 1993). Glacial drift, or Sleech as it is commonly known in the region, can be found underlying some regions with bedrock or coarse rock rubble in other. Area commonly used for agricultural purposes such as the rough grazing of sheep. Cruickshank and Tomlinson (1990) (Wilson and Hegarty, 1993) have shown that the region that Skerry Hill lies in, The Antrim Plateau, is one of a few areas located in Northern Ireland where peat failures are concentrated which implies this area is more susceptible to failure due to its location or other reasons.

The 3 months in the lead up to the failure were relatively dry with 90, 53 and 49% of average rainfall falling in each three months respectively according to data obtained for the Parkmore forest area, with November itself having 138% (P.Wilson, 1993). Daily rainfall figures showed that the rainfall in November was not consistent instead fell in 3 short intense periods, between 1st-3rd a total of 43.7 mm was recorded, 70.4 mm between 6th-8th and finally 42.8 mm between 17th-18th.

How the site was investigated
The scar and debris zones were surveyed by closed compass traverse during February 1992 (Wilson and Hegarty, 1993). Estimates of the areas affected by sliding where then derived, using this acquired data, and including the measurements of peat thickness, the volume of the failed peat was calculated. To survey the slide an abbey level, ranging poles and tape were used with long profiles being taken.

The botanical environment was investigated and recorded in June 1992 quadrants of size 1 m² were used to obtain a % cover value of the peat, then the corresponding Domin scale value was marked for each species that was monitored. A number of peat samples were obtained to determine the bulk density and degree of decomposition of the peat by applying the modified von Post scale.

Investigation findings and analysis
As previously mentioned the event was made up of two separate shallow landslide failures in a layer of blanket peat. Both of these failures lay on the east side of the slope but were not in the path of each other. They were both shallow translational slips and possessed two specific morphological
components one of which is a distinct scar or slip face and a debris tongue consisting of redeposited peat (Wilson and Hegarty, 1993). The outline of the two different slides is shown in Fig.2.

The total length of the slide was found to be 90 m from the top of the scar to the bottom of the debris tongue and was 50 m wide at its widest section. The area affected was 955 m$^2$, a minimum estimate, the debris tongue had an area of 1911 m$^2$. The scar margin thickness was 1.02 m giving the total volume of peat affected by the failure as 1949 m$^3$ (Dyes and Warburton, 2008). The failure slope had a gradient of around 12 degrees, a very high figure as most slope failures occur on slopes of 4-8 degrees (Boylan et al, 2008) and was located over a break slope below which the undisturbed blanket peat had a gradient of 5.5 degrees. The gradient of this slope could be the explanation of why shallow landslides occurred and not a thicker layer, as the steepness of the slope would not allow a thicker layer of peat to grow without failing first as happened in this scenario.

A partially filled drainage ditch of width and thickness 3 m and 0.5 m respectively was cut by the slide as it occurred at the break of the slope at the north of the slide. On the scar face a peat layer of 11 cm thickness still remains with a number of projecting basalt boulders there is also a few blocks of peat

Fig. 4. Outline of failure slides on Skerry Hill

The upper slide
The total length of the slide was found to be 90 m from the top of the scar to the bottom of the debris tongue and was 50 m wide at its widest section. The area affected was 955 m$^2$, a minimum estimate, the debris tongue had an area of 1911 m$^2$. The scar margin thickness was 1.02 m giving the total volume of peat affected by the failure as 1949 m$^3$ (Dyes and Warburton, 2008). The failure slope had a gradient of around 12 degrees, a very high figure as most slope failures occur on slopes of 4-8 degrees (Boylan et al, 2008) and was located over a break slope below which the undisturbed blanket peat had a gradient of 5.5 degrees. The gradient of this slope could be the explanation of why shallow landslides occurred and not a thicker layer, as the steepness of the slope would not allow a thicker layer of peat to grow without failing first as happened in this scenario.

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removing that did not fail with the rest of the slope. Water flowing down the scar surface was starting to erode and wash away the residual peat that remained. The blocks of peat which make up the debris tongue did not overturn on their journey down the failure surface and remain largely upright and not tilted. The blocks are separated by transverse linear fissures determined to be up to 2 m wide and 1 m deep, standing water could be found in these fissures and at the base of the tongue when the area was first examined.

The original ditch that ran through the slope had been displaced by 10-15 m downslope during the failure this actually improved the drainage of the ditch altering the vegetation profile on the surface. Downslope and lateral margins were well defined and undisturbed as there was no overflow of surface flow or seepage or peat saturated water away from the slides path of movement. Zone to the south of the slide was largely covered by stones and large isolated blocks of peat, further downslope of this the ground profile is possesses a peat layer of thickness 1 m. This site was thought to be the location of another peat slide which had occurred roughly 25 years earlier according to morphological evidence that was gathered and talking to the owner of the site who confirmed that an event had happened in that time frame. The remnants of this slides scar is devoid of any vegetation, apart from the margins where residual peat has started to spread onto the scars stony surface, narrow transverse fissures are evident in the layer of blanket peat found above this scar.

The lower Slide
This slide was slightly longer and narrower than the upper slide being of length 98 m and width 32 m, with an area of 689 m² and a debris tongue of 1000 m². An average peat thickness of 0.93 m² gave a total failure volume of 930 m³, although this was said to be seen as an overestimate as some of the peat blocks didn’t remain upright unlike the upper slide. The slip-face gradient has an inclination of 12° with the debris tongue resting on a less steep slope of 9°, a 13 m thick layer of peat remains on the slip surface along with projecting boulders and some isolated blocks of peat which resisted the failure. A drainage ditch similar to the upper slope defines the changes in the slope.

The upper area of the debris tongue is made up of large, upright or slightly tilted blocks separated by transverse fissures alike the slide upslope, it is not until further downslope that the blocks began to topple and break down into smaller pieces. A lot of bare, disintegrated peat is present in this area with the largest intact block measuring 4x3 m compared to the maximum of 12x3 m further up the failure surface. The debris tongue then stops abruptly as a step 1 m high and there can be no more seepage of peat found after this point. Again another older slide had occurred previously adjacent to the southern boundary; the scars surface is stony, extends 50 m downslope and has a debris tongue of twice the length of the present failure. A single curved fissure can be found upslope of both the past and present scars of length 30 m, further downslope and after the old scar ceases the drainage ditch from upslope reappears and continues.

Failure Mechanism
A process of elimination was used to try and determine what was the major factor in the failure event, certain causal factors could be ruled out at the start of the process as they were not compatible with the location for example there was no lakes, flush sites, peat cuttings close to the site that could have influenced the failure. There were also no drainage ditches above the site nor any piping at its margins. Factors which would have had influence are heavy rainfall, drainage ditches within the failure zone and gradient changes in the slope (Wilson and Hegarty, 1993).

As previously mentioned in the Pre-failure conditions section the rainfall conditions in the lead up to the event were not excessive and the site would have probably encountered similar conditions frequently in the past. For the rainfall to be the main causal factor in the failure, as is usually the case in peat failures, the rainfall that went unrecorded in November would have had to have been excessive and as this is not known it was determined that other local factors must also have had an influence on the failure.
A factor which can be directly linked with rainfall is the effect of the transverse drainage ditches; they can direct the excess rain and pore water into zones of potential instability. At the beginning the ditches could have in fact increased the slopes stability by removing excess rain water in a large downpour, as mentioned, therefore reducing the pore water pressure in the peat but as they were at the time partially infilled and vegetated they were thought to be acting more as a store for the drainage water rather than their more productive use of removing the water. This of course lowers the shear capacity of the slope and makes it more susceptible to failure. The role of the slopes gradient at the site was hard to evaluate in isolation due to no clear link between gradient and thickness and susceptibility to movement being available at the time. The failure of the peat blanket was then taken as a combination of a number of factors which included the slopes from and gradient.

The failure plane did not occur at the base of the peat between the peat layer and the underlying material, it in fact happened 10-20 cm above the peats base explaining why there was a thin layer of peat remaining on the slip faces after the failure. It was then suggested from this that a discontinuity must have existed between the basal and overlying layers of peat, examination of fresh exposures at the exposed margin then confirmed this as there was a clear visual and textural different between the two peat layers. The lower basal layer was black in appearance with no recognisable vegetation, measuring H8 and H9 on the von Post scale of decomposition indicating a very advanced stage of decomposition. The overlying layer was dark brown and reddish brown in appearance with a lot of recognisable plant material and ranged from H4-H7 on the von Post scale, giving a range of different degrees of decomposition from weak to heavy. The bulk density tests that were performed on the samples obtained from the site showed that the basal layer was indeed more compact than the overlying layer and as the failure plane is located at this boundary the slide resembles a bog flow according to Mitchell (1938) and Wilson & Hegarty (1993). The fibrous nature and lower density of the overlying layer is said to be the reason why the peat remained in large blocks and rafts throughout the slide with little liquefied peat being found throughout the site as fibrous peat has a greater shear strength relative to more humified layers.

It was found that the ground water table was not level with the grounds surface meaning the peat was undersaturated at the time of failure. This was based on seepage of peat saturated water beyond the margins of the debris tongue meaning that excess water present at the failure must have been dissipated quickly and infiltrated the vegetated area beneath the debris tongue. The case for undersaturation is also supported by the rainfall data obtained for the build-up for this event due to the relatively dry months beforehand followed by one above average month it was extremely unlikely that there would have been enough rainfall to full saturate the blanket peat. The fact that the peat was undersaturated also assists the peat in being able to stay intact as large blocks and rafts during failure as was seen in this scenario.

It was postulated that cracks would have been present in the layer of peat as the summer in the lead up to the event was dry. As stated in the casual factors section of this paper cracks within the peat structure can be extremely detrimental and when combined with a pattern of transverse fissures as found in the debris tongue, some of which contained a volume of standing water, it suggests that this mechanism was an extremely important causal factor.

**Summary**

- A combination of meteorological conditions, site factors and peat characteristics were the cause of the failure slides not one single major factor.

- Slopes that have been the location of previous failures are more susceptible to failure again than slopes that have yet to fail.

- The layer of blanket peat was undersaturated at the time of failure.
Failure plane didn’t occur at the base of the peat layer, instead it was found to be around 10-20cm above the peat base.

The upper and lower slides were similar in their nature although they had some differences, for example different levels of degradation of the blocks of peat that travelled down the failure slope. No two peat failures will ever be the same but can share similarities.

Prediction of mass movement in peat can be a difficult task but useful due to the damage that can be inflicted by a large failure.

Discussion

How the cases differed

A major linking factor between all three case studies was the influence on the peat’s failure by rainfall. It was found to be at minimum a contributing factor in all three of the cases, and being one of the major causal factors in the first study of Dooncarton Mountain. This case was under the most extreme weather conditions due to the thunder storm so as expected the rainfall was more influential than the other examples where as the rainfall wasn’t seen as exceptional in both cases it was only a factor when combined with other causal factors. These results relate well to the casual factors from Boylan et al, (2008) which states that ‘the most likely and most cited factor in all peat failures is high intensity rainfall and periods of prolonged rainfall.’ Through these studies it has been shown that the reason for this is the increased level of excess rainwater and pore water pressure decreases the shear strength of the peat material making it more susceptible to failure.

Another factor that was seen to be influential in case study 1 and 2, and closely linked to the rainfall intensity, is the effect of subsurface piping. In case study 1 it was deduced that although they can be causal factors they can also increase the drainage capacity of the peat, in case study 2 it was only the detrimental effect of the pipes that was evident, as the increase in pore pressures between adjacent pipes lowered the FOS of the peat. This second study also mentioned another factor, which wasn’t mentioned in the first, which was the distance of the feeding source from upslope, being the further upslope the pipes feeding source is the larger the effect from the pipes due to the increased hydrological pressure. There was no piping found on site for case study 3. Ditches were shown to have a similar effect to subsurface piping in that they concentrate excess surface flow and rainwater to areas of instability. An extra problem that occurs as a result of ditches, differing from pipes, is that they can cause the slope to be unsupported as in study 2, this was not accounted for in case study 1 but may have had a small contributing effect as it also contained a drainage ditch which traversed the site. Again like with pipes there was no ditches found on site at case study 3.

All three of the failure sites lay on a gradient of between 4-8° with the gradient of the lower scar at Cuilcagh Mountain having a gradient of 12°. This is in line with the statement by (Boylan et al, 2008) that failures are generally recorded on slopes of this magnitude. The underlying material was different in each of the cases a discontinuous iron pan with a doporite layer was the underlying material at Dooncarton Mountain, a clay substrate overlying a Namurian shale and sandstones at Cuilcagh Mountain and finally tertiary basalts and Dalradian schists at Skerry Hill. Each of the three layers produced a different effect to the cause of failure, the iron pan acted as a low friction surface that was also impermeable to water creating favourable conditions for a peat slide to occur. The clay substrate layer is a higher friction material than the iron pan and it was also more permeable to water, this could be one of the reasons why there was more degradation of the peat rafts when they travelled down the failure slope due to the extra fictional force from the drier and higher friction surface that was underlying it.
The presence of convexities is listed by Boylan et al, (2008) as a possible causal factor in peat failure. This was demonstrated in both study 1 and 2 but not in study 3, implying that while their presence does in fact make a failure more probable it is not a compulsory factor in the occurrence. Although study 3 did not have a convexity present it did have a greater inclination of slope than the other two cases, a slope inclination of 12°. This alike the convexities is a component of the slopes shape and structure which suggests this is a deciding factor in the failure of a slope as it is present in all 3 cases, albeit in different forms.

**How the investigations differed**

The most influential factor in the why and how the investigations differed is the period when they took place. The three case studies each took place in the years 2008, 2001 and 1993 respectively, the two that occurs post 2000 were able to use computer systems with analysis software to more closely analyse the site whereas the third case study could not make use of these systems as they were not available at the time. Instead methods such as closed compass traversing were used to survey the site, and while they can produce reliable and accurate results they can never be to the same level of accuracy as can be produced by a computer system.

The first two case studies use standard lab methods to determine the peats structural properties, for example the wet-dry bulk densities, but differ in that study 2 uses relationships from comparable materials to calculate the relationship between water content and negative pore pressure, which produces a large degree of inaccuracy due to the complexity of peats structure, whereas study 1 uses more finite methods giving a more accurate and reliable result. Study 3 is more simplistic in its approach to calculating structural values, for example using the von Post scale to determine the bulk density and degree of decomposition of the peat while this method can be effective it lacks the accuracy of direct testing of the material, this again is a result of the period in which the investigation took place. The investigation methods as a whole were more simplistic than the other two studies due to this aforementioned reason.

Study 2 and 3 were similar as they out more emphasis into the varying types of plant/vegetative species that had been growing in and around the failure site. Study 2 does not mention the method that they used to monitor this variable so the level of detail to which they investigated this topic is unknown, while study 3 uses a quadrant method to closely map the different types of species and their relative percentage coverage of the site. Study 1 does not put much weight into the species cover in their investigation, which could be problematic as we saw in study 2 specifically that some species need a higher than average water content in the peat to survive leading to the formation of subsurface piping; an important causal factor in failures.

**What can be learnt**

The main finding of this report is that peat failure is not dependant on any one causal factor; instead it is as a result of a combination of different factors. In all three case studies it was demonstrated that there was no one deciding factor that if had occurred individually would have resulted in a failure event. In certain scenarios there are factors which assert a greater influence on the failure than others, for example in case study one the most damaging factor was the intensity of the rainfall during the thunder storm with other factors such as the iron pan underlying the peat and drainage ditches also playing important roles in the peats failure.

We also learnt that there is still more investigation to be done for peat failures as not all is known and understood. A key example is the effect of subsurface pipes and drainage ditches as shown in study 1 they can improve drainage capacity on site keeping it from reaching full saturation which increase the likelihood of failure, but can also weaken the peat and cause it to be unsupported as occurs in study 2. This then requires new investigation and study to properly understand the effect that they have and why one factor can produce differing results.
Man-made influences are not as important as one would think with respect to peat failure, the cutting of drains and peat extraction (tine cuts). While they can be problematic as seen in DYKES (2008) the slope that included the tine cuts and boundary ditches was found to be equally unstable throughout. In other locations they found that failure had in fact occurred directly at either a cut or boundary ditch using this evidence it can be said that while they cannot solely cause a failure when combined with other causal factors they can present a problem, unless a possible extreme scenario occurred for example over extraction of the peat by the farmer by cutting too deep or too much. There was no tine cuts or boundary ditches present in either case study 2 or 3 to support this conclusion as they only contained natural factors. The majority of conditions for failure in peat can then said to be from natural causes. This can present a problem when trying to solve or predict these problems as natural variables such as the intensity of a rainfall period are unpredictable in their nature and so hard to plan preventative measures for.

**Possible Solutions**

As briefly mentioned due to the majority of causal factors being of natural origin not man made this makes them relatively difficult to prevent. To start with the man-made problems can be planned for in advance. For the peat extraction (tine cuts) a proper geotechnical assessment of the slope before any extraction takes place could be hugely beneficial as it would alert the peat farmer of possible faults and problematic sites. With this new information about the site the operator could draw up a reasonable plan in cooperation with the engineer, so that the peat could be in extracted in a way that does not pose a major risk to the slope. An example would be through controlling variables such as extraction depth and the path of the extraction along the site. While this is a more costly method for the customer it would possibly save them money in the long term by not having to deal with the extra costs, damage and other problems that are associated with a peat failure on his site. The same technique and principles could be applied to the problems associated with boundary ditches as they are very similar and closely linked to extraction.

Rainfall is the most complicated problem to deal with as it cannot be prevented or controlled and is one of the most influential causal factors with respect to peat failure. Due to this I would suggest that the best way to prepare for this problem would be through manipulation and controlling of the other factors so that when high intensity or a prolonged period of rainfall for example occurs the peat is at its maximum strength and has its maximum resistance to failure. One possible method of doing this would be through better drainage of the peat so the increase in pore pressure is kept as low as possible, implementing a drainage system to the peat layer could be effective and is discussed in more detail below with respect to the oversaturation problem as they are quite similar.

The slopes gradient is another factor that cannot be altered or controlled but there is a possibility of using peat extraction to limit the likelihood of their failure. By careful monitoring of a slopes gradient and the thickness of the overlying peats layer, the two most detrimental factors in this instance, it would be possible to highlight which slopes are at the highest risk of failure. Then it could be possible to harvest the peat on the higher risk slopes or before they get to the higher risk stage, this would regulate the thickness of the peat layer and stop it achieving a thickness whereby it becomes unstable and susceptible to failure. It also provides a source of revenue and incentive for the peat farmer so is an appealing solution. The ground conditions of the slope would be the deciding factor in whether this is a possible solution or not as not every slope would be suitable for peat extraction.

The problem of oversaturation of the peat again like the intensity of the rainfall is complicated and difficult to solve. The possibility of implementing overflow drains could be costly and therefore not economically viable. Research would also have to be done to show that a man-made drainage system for peat wouldn’t have the same deteriorating effects as a natural drain, making the slope more susceptible to failure. This again would be a costly and time consuming process. A similar process has been implemented in England to lower the water table in peatlands with the aim of improving the productivity of the land (Wallage, Holden and McDonald, 2006). This process was successful but was
associated with some negative environmental consequences such as heightened flood risk and a faster rate of loss of dissolved organic carbon.

Kazemain, Huat, Prasad and Barghchi (2011) put forward some practical solutions based on the geotechnical properties of peat. Ground compression increases the density of peat and reduces the thickness of the layer, these both have a positive influence by reducing the settlement of peat when constructed on and as previously mentioned the thicker a layer is the more likely it is to fail. Soil replacement is very effective as the peat is replaced with a soil with far superior engineering properties but is size dependent, the larger the site the less economical it becomes. They found the best solution to be a chemical admixture of cement and lime applied as lime-cement columns in the peat layer, the chemicals have been found to react with the peat to increase it shear strength.

**Conclusion**

The main finding of this report is that peat failure is usually as a result of multiple causal factors working in unison and not merely one individual factor by itself. There are many different combinations of different factors that can cause a failure to occur as there is no one condition solely responsible for failure. All three case studies complied with this finding; Study 1 had one factor that was significantly more influential, intensity of rainfall, but still failed as a result of it combining with other factors such as the underlying material. The presence and significance of rainfall in all three studies suggested that it is the most important causal factor with regards to peat failure.

One main contradiction that was found in study 1 shows that more research is needed into this topic; this was the effect on subsurface pipes and drains on failure. They were seen to increase the drainage capacity of the slope in certain areas, increasing its resistance to failure, and decrease its resistance in others by increasing pore pressure and other factors. They also only had a degrading in study 2, with an added effect of causing the peat structure to be unsupported which was not evident in study1.

It should be noted that while they were not mentioned in the methods of the case studies the most common method for attaining peat characteristics such as the Liquid and Plastic Limit is by using the Atterberg Limit test (O’Kelly, 2015). The problem with this is that in 2015 Brendan C. O’Kelly postulated that this was not correct. He found that the sample preparation method used in this testing altered the material to an extent that a considerable difference between the recorded and actual values for LL and PL. If the case studies had then used this method it would produce an uncertainty in the results, although unlikely to change the findings of the studies it would affect their accuracy, due to the use of these limits in determining other structural properties of a material.

The amount of solutions that are available to this problem are limited as most of the causal factors are of natural origin and are hard to regulate, for example rainfall intensity and slope gradient, due to this my idea was to manipulate the peat itself instead of trying to control and regulate these conditions so that it is always at its maximum strength thereby having the maximum resistance to failure. The solutions put forward in this paper, in my opinion, have the potential to reduce the likelihood and frequency of failures if properly implemented.

**Bibliography**


