Geotechnical Aspects of Peat Dams on Bog Land

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Abstract

Boglands are wetlands formed by the gradual accumulation of decaying plant material. Many bogs have been damaged to varying degrees by anthropogenic activities such as drainage schemes, afforestation and harvesting of peat. The conservation of a bog requires the careful management of the groundwater to support plant growth and to prevent drying out of the peat material. Drainage and cutaway areas cause subsidence that tends to propagate across the bog. One conservation approach involves the construction of peat dams along the bog perimeter at an affected site. This paper reviews a case study at Raheenmore bog (Ireland) where a series of peat dams were constructed. A local slope failure of one of the peat dams occurred after construction. The dams were studied with the aim of identifying the cause of failure. On-site information was reviewed and a series of laboratory tests were conducted on undisturbed and remoulded peat specimens. Numerical back-analysis of the failed peat dam was carried out.

Introduction

Raised bogs, characterised by a domed relief, originated after the last glaciation over 10,000 years ago when the lakes formed by the glacial melt waters were colonised and gradually filled in with fen vegetation and decaying plant material. Raised bogs have been threatened by drainage schemes used to improve the land for agricultural use, afforestation or the harvesting of peat. Plant root activity ceases when the groundwater level falls about 10 cm below the ground surface. The bog surface subsides in response until the acrotelm (upper growing peat layer) reaches the new equilibrium groundwater level thereby allowing plant growth to recommence. However, there are also limits to the steepness of the slopes that will support sphagnum moss growth.

In the past 20 years, the conservation of semi-intact raised bogs has been highlighted by more stringent environmental policy and legislation, particularly concerning Special Areas of Conservation. For example, only about 19% of the 1.3 million hectares of peatland that originally covered Ireland remains relatively intact. Many engineering solutions have been considered to reverse the damage to protected raised bog ecosystems. One method that was used at Raheenmore bog (Ireland) was the construction of peat dams along the bog perimeter to pond surface water that would re-saturate and regenerate

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the vegetation in locally damaged areas. The purpose of the peat dams was also to arrest the propagation of the subsidence initiated by the perimeter drainage.

Case study

Raheenmore bog (Figure 1a) located in County Offaly, Ireland, is a designated Nature Reserve, 162 hectares in area with peat depths of up to 15 m, which are underlain by lacustrine clay. The bog has been effected by man-made drainage along sections of its perimeter.

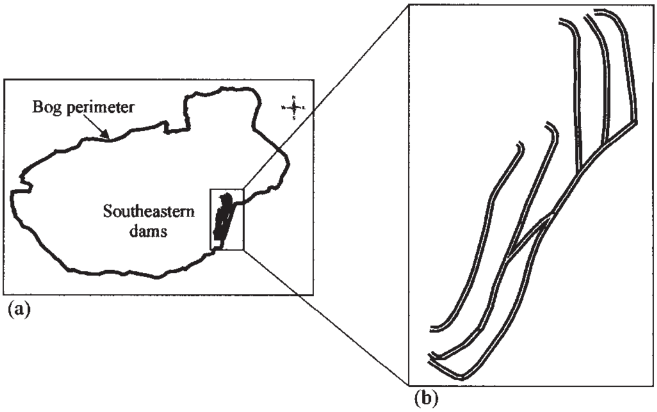

Figure 1 – (a) Raheenmore bog. (b) South-eastern peat dams.

Following a series of geological and hydrogeological studies completed by the Irish-Dutch Raised Bog Study (Streefkerk and Zandstra, 1994), a site was chosen at the south-eastern part of Raheenmore bog for the construction of a series of semi-concentric peat dams (Figure 1b). The dams, 0.5 to 5.0 m in height, were constructed during the summers of 1994 and 1995 using peat material that was at different stages of biodegradation, namely; very slightly decomposed (H2 to H3 on the von Post classification scale), slightly decomposed (H3 to H5), and highly decomposed (H7 to H8). The von Post classification system (von Post and Granlund, 1926) characterises the peat material in terms of its degree of biodegradation on a scale of H1 to H10, with H10 being the most strongly degraded, amorphous material. Figure 2 shows a typical cross-section of a dam constructed of slightly decomposed peat. Figure 3 shows the cross-section of a dam constructed of strongly decomposed peat.

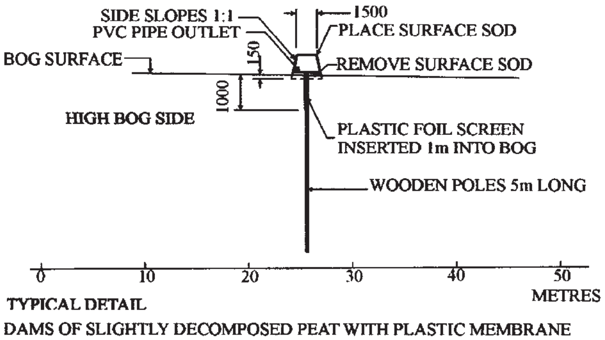

Figure 2 – Cross section of dam constructed of slightly decomposed peat (Bennett, 1998).

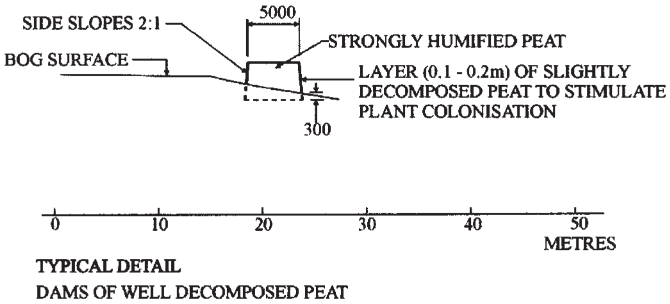

Figure 3 – Cross section of dam constructed of strongly decomposed peat (Bennett, 1998).

These dams were designed based on the experiences from the construction of similar dams at the Bargerveen Nature Reserve (The Netherlands). Wooden poles, 5 m in length, were driven vertically into the ground under the dams that were constructed of the slightly decomposed peat material to increase bearing stability.

Performance of dams at Raheenmore

A local slope failure of one of the dams occurred in December 1998, about four years after the completion of construction. A large flow of water and peat debris was discharged and covered an area of about 0.36 hectares (Figure 4).

Tension cracks were evident around the area of the breach. Large-scale vertical and horizontal displacements occurred with the crest of the dam having been displaced downslope by 1.5 m. On-site monitoring ceased prior to the slope failure so it was difficult to identify with certainty the cause of failure.

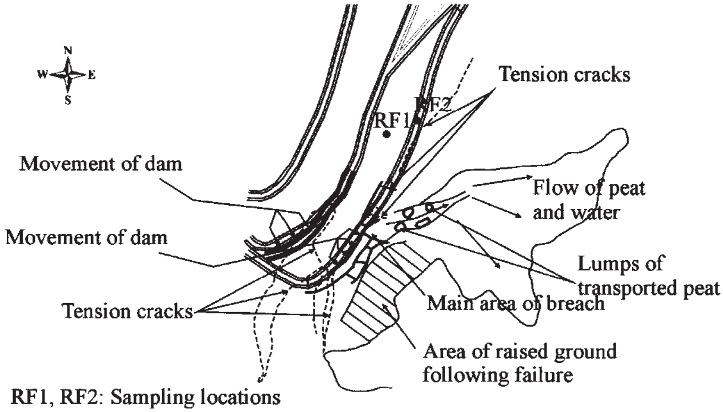

Figure 4 – Extent of dam failure.

Material properties and test programme

Peat samples were taken at locations RF1 (*in-situ* peat) and RF2 (remoulded used to construct the dam) shown in Figure 4. The samples were taken from about 1.0 m below ground level by pushing a thin-walled sampling tube, 100 mm in diameter and 1.0 m in length, into the ground. Some index properties of the peat material are listed in Table 1.

Table 1 –Index properties of the peat material.

Location	von Post classification	Water content (%)	Specific gravity	Mass loss on ignition (%)
RF1	H4	1170	1.42	98
RF2	H4	590	1.46	92

The water content values were determined by oven drying specimens of the peat material at 105°C. The mass loss on ignition values were determined by igniting dry peat material at 440°C. Location RF2 had a lower ignition loss since the peat material used in the construction of the dam was sourced from nearer the bog perimeter and included some clay material. The specific gravity (G) values were estimated using the equation $G=3.8/(0.013N+1.4)$ where N (%) = the mass loss on ignition (Hobbs, 1986).

Landva and La Rochelle (1983) reported that the ring shear test was the most reliable in determining the effective stress shear strength parameters of peat. A programme of consolidated-drained shearbox and ring shear tests was carried out. The shearbox specimens were 101.6 mm in diameter and 20.0 mm in height. The ring shear specimens had an outer diameter of 50.0 mm and an inner diameter of 35.0 mm. The specimens were consolidated under applied vertical stresses of 10, 20 and 40 kPa. The specimens were then sheared slowly at a rate of 0.00975 mm/minute in the shearbox apparatus and 0.096 deg/minute in the ring shear apparatus, which allowed full dissipation of the excess porewater pressures.

Laboratory test results

The stress-strain behaviour of the peat specimens measured using the shearbox apparatus is shown in Figure 5. The results from the ring shear tests are shown as shear stress versus angular rotation in Figure 6. A Mohr-Coulomb analysis (Figure 7) indicated that the ring shear and shearbox apparatus gave similar effective stress shear strength parameters of $c' = 0$ and $\phi' = 38^{\circ}$. Farrell and Hebib (1998) reported similar values from shearbox and ring shear tests on the Raheenmore peat material.

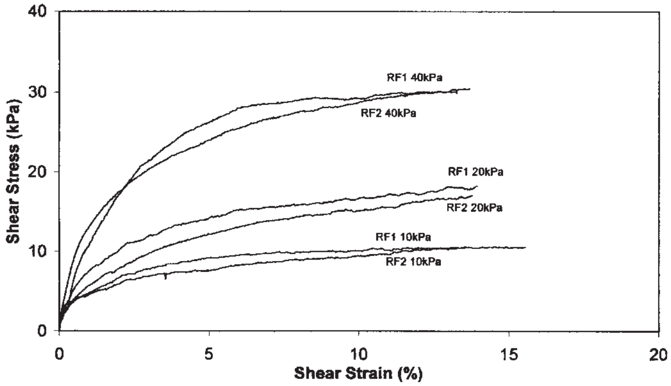

Figure 5 – Shear stress versus shear strain data from shearbox tests.

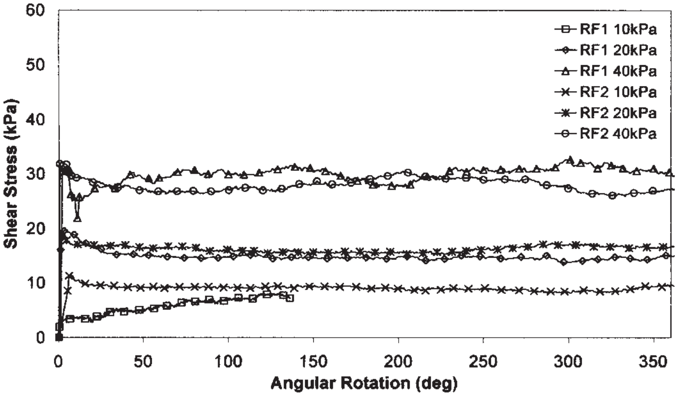

Figure 6 – Shear stress versus angular rotation from ring shear tests.

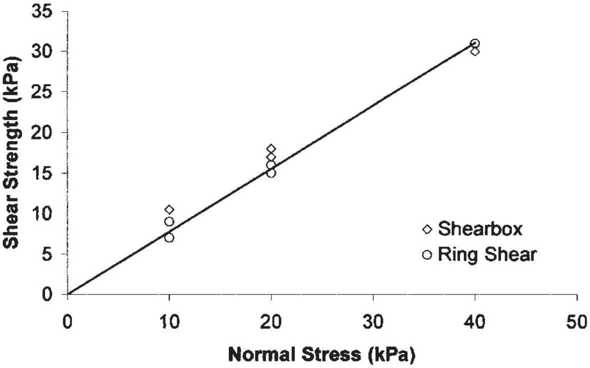

Figure 7 – Shear stresses versus effective normal stress plot.

Numerical modelling

The Raheenmore dam was modelled using the finite element package PLAXIS (version 8.2). Table 2 shows the soil input parameters used for the analysis. The analysis indicated that slope instability would not occur under these conditions (factor of safety of 1.12). However, the analysis predicted some vertical and lateral movements of the peat dam (Figure 8).

Table 2 – Soil properties for PLAXIS analysis.

Soil	Saturated unit weight (kN/m^3) γ_{sat}	Horizontal permeability (m/day) k_x	Vertical permeability (m/day) k_y	Young's modulus (kN/m^2) E_{ref}	Poisson's ratio ν	Cohesion (kN/m^2) c_{ref}	Friction angle (deg) ϕ'
Dam peat (RF2)	11.4	10^{-4}	10^{-5}	420	0.2	0	38
Bog foundation (RF3)	10.8	10^{-4}	10^{-5}	420	0.2	0	38
Clay	21.0	10^{-8}	10^{-8}	2000	0.35	10	30

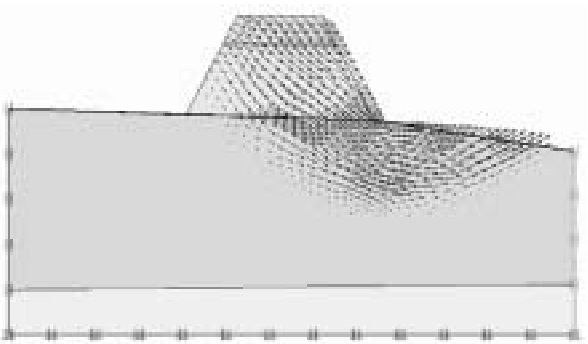

Figure 8 – Ground displacements predictions from PLAXIS analysis.

van Baars (2005) presented a case study involving the translational failure of a canal dyke constructed of peat material in The Netherlands. The failure occurred due to the decrease in the weight of the dyke as a result of drying out of the peat material near the crest of the dyke. At Raheenmore bog, the dam crest would also have dried out during extended periods of dry weather. The effect of the increase in the horizontal pressure that acted behind the dam during sudden rainfall events was considered in the horizontal and vertical stability analysis according to method of van Baars (2005).

Figure 9 shows a cross section of the dam close to the failure location. The maximum head of water retained by the dam was limited to 2.5 m by a pipe that allowed the overflow to discharge to a point in front of the dam. There were concerns that the water exiting this pipe may have eroded the front toe of the dam thereby further increasing the likelihood of slope instability.

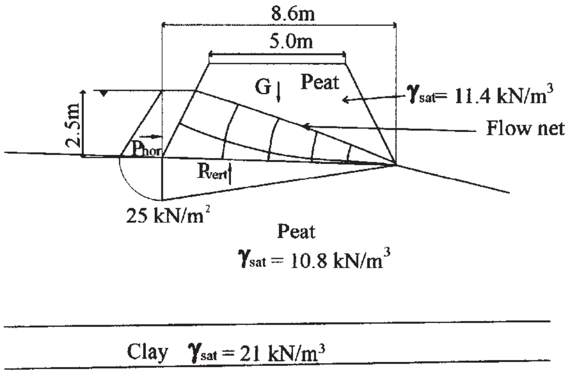

Figure 9 – Cross section of dam.

Horizontal and vertical stability

The total cross-sectional area of the dam (I_{tot}) was 24 m^2. If the peat material had been saturated over the full cross-sectional area, the weight of the dam ($G_{sat} = I_{tot} \times \gamma_{sat}$) would have equalled 274 kN/m run. The flow net in Figure 9 shows the general flow path through the dam and the zone above which drying out of the peat material could have occur during extended periods of dry weather. If this zone had dried out, the weight of the dam ($G_{unsat} = G_{sat} - l_{unsat}$ x $(\gamma_{sat} - \gamma_{dry})$) would have been reduced to 144 kN. The hydrostatic uplift beneath the dam ($P_{vert} = 0.5$ x p x l) was 108 kN. The hydrostatic force ($P_{hor} = 0.5$ x γ x h^2) acting behind the dam with the water level at the overflow level would have equalled 31 kN. If the water level had fallen by just 1.0 m, then the hydrostatic force would have reduced to 11 kN. The limiting horizontal shear resistance mobilised over the base of the peat dam was determined using the laboratory-measured c' and ϕ' values in the following equation: $F_{max} = l.c' + (G - P_{vert})$ x tan ϕ'. The safety factor (SF) was calculated as F_{max}/P_{hor}, with failure occurring for SF < 1.0. Table 3 shows the safety factors calculated for the different scenarios.

The safety factor for the case of the water level equal to the overflow level and the crest of the dam in an unsaturated state was below 1.0 indicating that failure would occur. A large rainfall event did occur prior to failure of the Raheenmore dam in December 1998 that would have increased the hydrostatic force acting behind the dam. Tension cracks and the possibility of erosion and undermining of the front toe of the dam by the water discharging from the overflow pipe could have reduced the safety factor even further.

Table 3 – Safety factors for different scenarios.

Water level	Peat at crest	P_{hor}	P_{vert}	G	F_{max}	Safety factor
High	Saturated	31	108	274	129.7	4.2
High	Unsaturated	31	108	144	28.1	0.9
Low	Saturated	11	108	274	129.7	11.5
Low	Unsaturated	11	108	144	28.1	2.5

Summary and conclusions

Peat dams used in the conservation of raised bogs are generally constructed on the *in-situ* bog foundation. The dams at Raheenmore bog (Ireland) were designed from experience of dam construction at Bargerveen Nature Reserve (The Netherlands). Translational failure is of major concern and is not always considered in the design of peat dams. A local translational failure occurred at one of the Raheenmore dams about 4 years after the completion of construction. Shearbox and ring shear tests carried out on peat material indicated effective stress shear strength parameters c' = 0 and $\phi' = 38^o$. The ground model and soil parameters were inputted into a finite element package to determine the factor of safety on slope instability. A factor of safety on slope instability of 1.12 was obtained for a classical circular slip failure indicating that the dam should have been stable. However, further analysis using the same soil parameters in horizontal and vertical stability calculations after van Baars (2005) indicated a factor of safety of less than 1.0 for the case of a dried out zone near the dam crest and a high water level acting behind the dam. Tension cracks evident in the failure location and piping underneath the dam may have also been contributing factors. Translational failure is a principle mode of failure for peat dams built on bogland and should always be considered in design.

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